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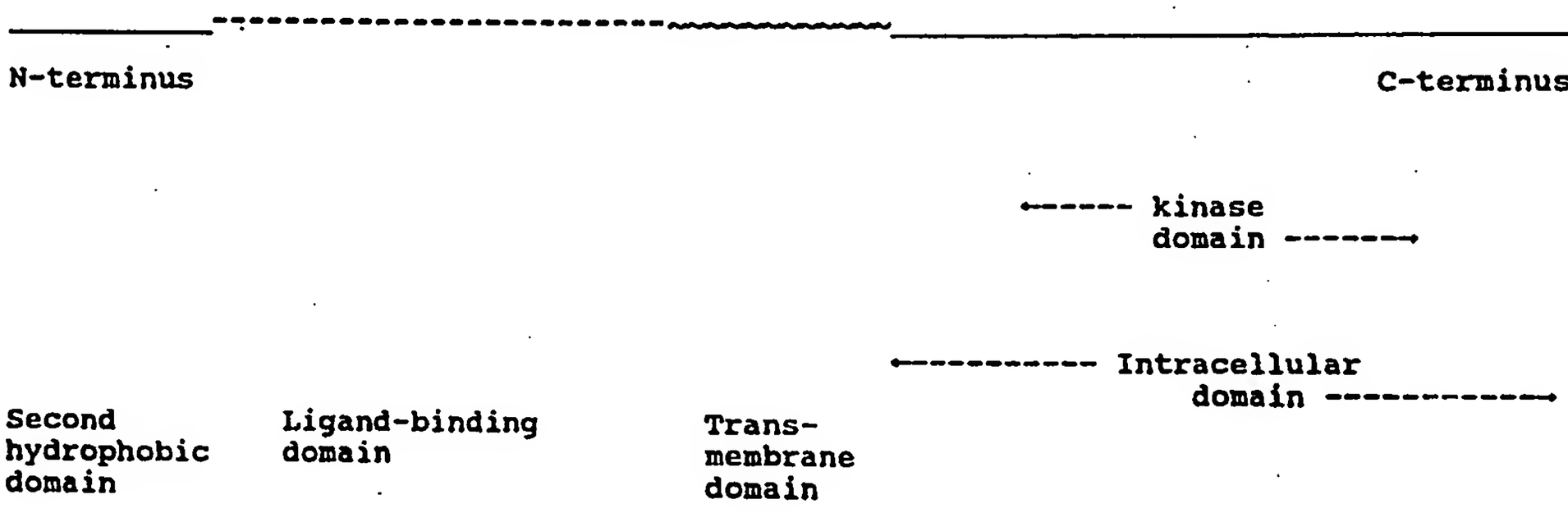

(57) Abstract

In accordance with the present invention, there are provided novel receptor proteins characterized by having the following domains, reading from the N-terminal end of said protein: an extracellular, ligand-binding domain, a hydrophobic, trans-membrane domain, and an intracellular, receptor domain having serine kinase-like activity. The invention receptors optionally further comprise a second hydrophobic domain at the amino terminus thereof. The invention receptor proteins are further characterized by having sufficient binding affinity for at least one member of the activin/TGF-β superfamily of polypeptide growth factors such that concentrations of $\leq$ 10 nM of said polypeptide growth factor occupy $\geq$ 50 % of the binding sites of said receptor protein. A presently preferred member of the invention superfamily of receptors binds specifically to activins, in preference to inhibins, transforming growth factor-β, and other non-activin-like proteins. DNA sequences encoding such receptors, assays employing same, as well as antibodies derived therefrom, are also disclosed.

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CLONING AND RECOMBINANT PRODUCTION OF RECEPTOR(S) OF THE ACTIVIN/TGF-β SUPERFAMILY

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FIELD OF THE INVENTION

The present invention relates to receptor proteins, DNA sequences encoding same, and various uses therefor.

BACKGROUND OF THE INVENTION

Activins are dimeric proteins which have the ability to stimulate the production of follicle stimulating hormone (FSH) by the pituitary gland. Activins share a common subunit with inhibins, which inhibit FSH secretion.

Activins are members of a superfamily of polypeptide growth factors which includes the inhibins, the transforming growth factors-ß (TGF-ß), Mullerian duct inhibiting substance, the Drosophila decapentaplegic peptide, several bone morphogenetic proteins, and the Vg-related peptides.

As a result of their extensive anatomical distribution and multiple biological actions, members of this superfamily of polypeptide growth factors are believed to be involved in the regulation of numerous biological processes. Activin, for example, is involved in the proliferation of many tumor cell lines, the control of secretion and expression of the anterior pituitary hormones (e.g., FSH, GH and ACTH), neuron survival, hypothalamic oxytocin secretion, erythropoiesis, placental and gonadal steroidogenesis, early embryonic development, and the like.

Other members of the activin/TGF-ß superfamily of polypeptide growth factors are involved in the regulation of cell function and cell proliferation for numerous cell types, in adults and embryos. For example, cells which are subject to regulation by one or more members of the activin/TGF-ß superfamily of polypeptide growth factors include mesenchymal cells, muscle cells, skeletal cells, immune cells, hematopoietic cells, steroidogenic cells, endothelial cells, liver cells, epithelial cells, and the like.

Chemical cross-linking studies with a number of cell types suggests that multiple binding sites (i.e., receptors) exist on the surface of cells. However, little is known about the structure of these receptors, or about the second messenger signalling systems that they employ. It would be desirable, therefore, if the nature of these poorly characterized receptor proteins could be more fully understood.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, we have identified and characterized members of a new superfamily of receptor proteins which comprise three distinct domains: an extracellular, ligand-binding domain, a hydrophobic,

trans-membrane domain, and an intracellular, receptor domain having serine kinase-like activity.

Also provided are DNAs encoding the above-described receptor proteins, and antibodies thereto, as well as bioassays, therapeutic compositions containing such proteins and/or antibodies, and applications thereof.

The DNAs of the invention are useful as probes for the identification of additional members of the invention superfamily of receptor proteins, and as coding sequences which can be used for the recombinant expression of the invention receptor proteins, or functional fragments thereof. The invention receptor proteins, and antibodies thereto, are useful for the diagnosis and therapeutic management of carcinogenesis, wound healing, disorders of the immune, reproductive, or central nervous systems, and the like.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a schematic diagram of receptors of the invention and the various domains thereof.

Figure 2 outlines the strategy used for expression cloning of a receptor of the activin/TGF-β receptor superfamily.

Figure 3 is a schematic of two mouse activin receptor clones. The top line of the figure is a restriction map, in kb, of mActR1 and mActR2, with numbering starting from bp 1 of mActR2. The dotted line in the figure represents 5' untranslated sequences present only in mActR1. The middle lines present a schematic representation of two activin receptor cDNA clones. Boxes represent coding sequences---black is the signal peptide, white is the extracellular ligand-binding domain, gray is

the transmembrane, and the intracellular kinase domain is hatched. Amino acids are numbered beneath the schematics.

Figure 4 presents a comparison between activin receptor and daf-1 [a C. elegans gene encoding a putative receptor protein kinase (with unknown ligand); see Georgi, et al., Cell 61: 635-645 (1990)]. Conserved residues between the activin receptor and daf-1 are highlighted; conserved kinase domain residues are designated with an "*".

Figure 5A summarizes results of ^{125}I activin A binding to COS cells transfected with pmActR1. Binding was competed with unlabeled activin A. For the runs reported herein, total binding was 4.6% of input cpm, non-specific binding was 0.9% of input cpm, and therefore the specific binding was 3.7% of input cpm. Data are shown as % specific binding, normalized to 100%. The inset presents a Scatchard analysis of the data [Ann. NY Acad. Sci. 51: 660-672 (1979)].

Figure 5B summarizes results of ^{125}I activin A binding to COS cells transfected with pmActR2. Binding was competed with unlabeled factors as indicated in the figure. For the runs reported herein, total binding was 3.4% of input cpm, non-specific binding was 0.9% of input cpm, and therefore the specific binding was 2.5% of input cpm. Data are shown as % specific binding, normalized to 100%.

Figure 6 is a phylogenetic tree, comparing the relationship of the activin receptor kinase domain to other protein kinases. To construct the tree, the catalytic domains of representative sequences were empirically aligned and evolutionary relatedness was calculated using an algorithm designed by Fitch and Margoliash [Science 155: 279-284 (1967)], as implemented by Feng and Doolittle [J. Mol. Evol. 25: 351-360 (1987)]. Known subfamilies of

kinases are indicated in the figure. For those sequences that had similarity scores (i.e., a relative sequence identity) of at least 4 standard deviations above the mean (in comparison with all other known kinase sequences), the percent identity with the activin receptor is indicated. For further detail on kinase sequences, the reader is referred to Hanks and Quinn, Meth. Enzymol. 200: 38-62 (1991).

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, there is provided a novel superfamily of receptor protein(s) characterized by having the following domains, reading from the N-terminal end of said protein:

an extracellular, ligand-binding domain,
a hydrophobic, trans-membrane domain, and
an intracellular domain having serine kinase-like activity.

The novel receptor protein(s) of the invention optionally further comprise a second hydrophobic domain at the amino terminus thereof.

As employed herein, the phrase "extracellular, ligand-binding domain" refers to that portion of receptors of the invention which has a high affinity for ligand, and which, when associated with a cell, resides primarily outside of the cell membrane. Because of its location, this domain is not exposed to the processing machinery present within the cell, but is exposed to all components of the extracellular medium. See Figure 1.

As employed herein, the phrase "hydrophobic, trans-membrane domain" refers to that portion of receptors of the invention which traverses the cell membrane, and serves as a "bridge" between the extracellular and

intracellular domains of the receptor. The hydrophobic nature of this domain serves to anchor the receptor to the cell membrane. See Figure 1.

As employed herein, the phrase "intracellular domain having serine kinase-like activity" refers to that portion of receptors of the invention which resides within the cytoplasm, and which embodies the catalytic functionality characteristic of all receptors of the invention. See Fig 1.

The optional second hydrophobic domain, positioned at the amino terminus of receptors of the invention, comprises a secretion signal sequence which promotes the intracellular transport of the initially expressed receptor protein across the Golgi membrane. See Figure 1.

Members of the invention superfamily of receptors can be further characterized as having sufficient binding affinity for at least one member of the activin/TGF-ß superfamily of polypeptide growth factors such that concentrations of ≤ 10 nM of said polypeptide growth factor occupy ≥ 50% of the binding sites of said receptor protein.

Binding affinity (which can be expressed in terms of association constants, Ka, or dissociation constants, Kd) refers to the strength of interaction between ligand and receptor, and can be expressed in terms of the concentration of ligand necessary to occupy one-half (50%) of the binding sites of the receptor. A receptor having a high binding affinity for a given ligand will require the presence of very little ligand to become at least 50% bound (hence the Kd value will be a small number); conversely, receptor having a low binding affinity for a given ligand will require the presence of high levels of ligand to become 50% bound (hence the Kd value will be a large

number).

Reference to receptor protein "having sufficient binding affinity such that concentrations of said polypeptide growth factor less than or equal to 10 nM (i.e., ≤ 10 nM) occupy ≥ 50% (i.e., greater than or equal to one-half) of the binding sites of said receptor protein" means that ligand (i.e., polypeptide growth factor) concentration(s) of no greater than about 10 nM are required in order for the ligand to occupy at least 50% of the active sites of said receptor, with much lower ligand concentrations typically being required. Presently preferred receptors of the present invention have a binding affinity such that ligand concentration(s) in the range of only about 100 - 500 pM are required in order to occupy (or bind to) at least 50% of the receptor binding sites.

Members of the invention superfamily of receptors can be divided into various subclasses, based on the approximate size of the crosslinked complexes obtained when radiolabeled activin is chemically crosslinked to cell extracts [see, for example, Example VI below, or Mathews and Vale in Cell 65:973-982 (1991)]. Type I activin/TGF-β receptors are those which form a crosslinked complex of about 65 kD with activin; Type II receptors are those which form a crosslinked complex of about 80-85 kD with activin; while Type III, Type IV and the like receptors are those which form crosslinked complexes with activin having molecular weights greater than about 100 kD.

Each member of a given subclass is related to other members of the same subclass by the high degree of homology (e.g., >80% overall amino acid homology; frequently having >90% overall amino acid homology) between such receptors; whereas members of a given subclass differ from members of a different subclass by the lower degree of homology (e.g., at least about 30% up to 80% overall amino

acid homology; with in the range of about 40% up to 90% amino acid homology specifically in the kinase domains thereof) between such receptors. Typically, related receptors have at least 50% overall amino acid homology; with at least about 60% amino acid homology in the kinase domains thereof. Preferably, related receptors are defined as those which have at least 60% overall amino acid homology; with at least about 70% amino acid homology in the kinase domains thereof.

Based on the above criteria, the receptors described herein are designated Type II receptors, with the first discovered Type II receptor (i.e., the mouse-derived activin receptor) being designated ActRII, while subsequently identified Type II receptors which are not homologs of ActRII (because while clearly related by size and some sequence homology, they differ sufficiently to be considered as variants of ActRII), are designated ActRIIB, ActRIIC, etc.

Presently preferred members of the invention superfamily of receptors are further characterized by having a greater binding affinity for activins than for inhibins. Such receptors are frequently also observed to have:

substantially no binding affinity for transforming growth factors-ß, and

substantially no binding affinity for non-activin-like proteins or compounds.

Additional members of the invention superfamily of receptors are further characterized by having a greater binding affinity for inhibins than for activins or TGF-ßs.

Additional members of the invention superfamily of receptors are further characterized by having a greater binding affinity for TGF-ßs than for activins or inhibins.

As employed herein, "activin" refers to activin A (a homodimer of two inhibin β_A subunits), activin B (a homodimer of two inhibin β_B subunits), activin AB (a heterodimer composed of one inhibin β_A subunit and one inhibin β_B subunit); "inhibin" refers to inhibin A (composed of the inhibin α subunit and an inhibin β_A subunit), inhibin B (composed of the inhibin α subunit and an inhibin β_B subunit); "transforming growth factor ß or TGF-ß" refers to TGF-ß1 (a homodimer of two TGF-ß1 subunits), TGF-ß2 (a homodimer of two TGF-ß2 subunits), TGF-ß3 (a homodimer of two TGF-ß3 subunits), TGF-ß4 (a homodimer of two TGF-ß4 subunits), TGF-ß5 (a homodimer of two TGF-ß5 subunits), TGF-ß1.2 (a heterodimer of one TGF-ß1 subunit and one TGF-ß2 subunit), and the like.

Transforming growth factors-β (TGF-βs) are members of the activin/TGF-β superfamily of polypeptide growth factors. TGF-ßs are structurally related to activins, sharing at least 20-30% amino acid sequence homology therewith. TGF-ßs and activins have a substantially similar distribution pattern of cysteine residues (or substitution) throughout the peptide chain. Furthermore, both polypeptides, in their active forms, are dimeric species.

As employed herein, the term "non-activin-like" proteins refers to any protein having essentially no structural similarity with activins (as defined broadly herein).

Preferred members of the invention superfamily of receptors comprise those having in the range of about 500 amino acids, and are further characterized by having the following designated sizes for each of the domains thereof, reading from the N-terminal end of said receptor:

the extracellular, ligand-binding domain preferably will have in the range of about 114-118

amino acids,

the hydrophobic, trans-membrane domain preferably will have in the range of about 23-28 amino acids, beginning at the carboxy terminus of the extracellular domain, and

the intracellular domain having kinase-like activity preferably will have in the range of about 345-360 amino acids, beginning at the carboxy terminus of the hydrophobic, trans-membrane domain.

Receptors of the invention optionally further comprise a second hydrophobic domain having in the range of about 16-30 amino acids at the extreme amino terminus thereof (i.e., at the amino terminus of the extracellular, ligand-binding domain). This domain is a secretion signal sequence, which aids the transport of invention receptor(s) across the cell membrane. Exemplary secretion signal sequences include amino acids 1-19 of Sequence ID No. 1, amino acids 1-20 of Sequence ID No. 3, and the like. Such secretion signal sequences can be encoded by such nucleic acid sequences as nucleotides 71-127 of Sequence ID No. 1, nucleotides 468-527 of Sequence ID No. 3, and the like.

Members of the invention superfamily of receptors can be obtained from a variety of sources, such as, for example, pituitary cells, placental cells, hematopoietic cells, brain cells, gonadal cells, liver cells, bone cells, muscle cells, endothelial cells, epithelial cells, mesenchymal cells, kidney cells, and the like. Such cells can be derived from a variety of organisms, such as, for example, human, mouse, rat, ovine, bovine, porcine, frog, chicken, fish, mink, and the like.

Presently preferred amino acid sequences encoding receptor proteins of the invention include the sequence set forth in Sequence ID No. 2 (which represents a mouse activin receptor amino acid sequence), a modified form of

Sequence ID No. 2 wherein the arginine at residue number 39 is replaced by a lysine, the isoleucine at residue number 92 is replaced by a valine, and the glutamic acid at residue number 288 is replaced by a glutamine (which modified form of Sequence ID No. 1 is referred to hereinafter as "Sequence ID No. 1'", and represents a human activin receptor amino acid sequence), and the sequence set forth as Sequence ID No. 4 (which represents a Xenopus activin receptor amino acid sequence), as well as functional, modified forms thereof. Those of skill in the art recognize that numerous residues of the above-described sequences can be substituted with other, chemically, sterically and/or electronically similar residues without substantially altering the biological activity of the resulting receptor species.

In accordance with another embodiment of the present invention, there is provided a soluble, extracellular, ligand-binding protein, further characterized by:

having sufficient binding affinity for at least one member of the activin/TGF-ß superfamily of polypeptide growth factors such that concentrations of ≤ 10 nM of said polypeptide growth factor occupy ≥ 50% of the binding sites on said receptor protein, and

having at least about 30% sequence identity with respect to:

the sequence of amino acids 20-134 set forth in Sequence ID No. 2;

the sequence of amino acids 20-134 set forth in Sequence ID No. 2, wherein the arginine residue at position number 39 is replaced by a lysine, and the isoleucine at residue number 92 is replaced by a valine; or

the sequence of amino acids 21-132 set forth in Sequence ID No. 4.

Presently preferred soluble, extracellular, ligand-binding proteins contemplated by the present invention can be further characterized by having at least about 50% sequence identity with respect to:

the sequence of amino acids 20-134 set forth in Sequence ID No. 2;

the sequence of amino acids 20-134 set forth in Sequence ID No. 2, wherein the arginine residue at position number 39 is replaced by a lysine, and the isoleucine at residue number 92 is replaced by a valine; or

the sequence of amino acids 21-132 set forth in Sequence ID No. 4;

with the presently most preferred soluble, extracellular, ligand-binding proteins having at least about 80% sequence identity with respect to the above-referenced fragments of Sequence ID Nos. 2 or 4 .

Members of the class of soluble, ligand-binding proteins contemplated by the present invention may be divided into various subclasses, as previously described, wherein members of one subclass may have a greater binding affinity for activins than for inhibins and/or TGF-ßs; or alternatively, members of another subclass may have a greater binding affinity for inhibins than for activins and/or TGF-ßs; or alternatively, members of yet another subclass may have a greater binding affinity for TGF-ßs than for activins and/or inhibins. It is, of course, understood by those of skill in the art, that members of more than one subclass may have a greater binding affinity for one member of the activin/TGF-ß superfamily of polypeptide growth factors, relative to other members of the superfamily.

Presently preferred soluble, extracellular, ligand-binding proteins of the present invention are further characterized by:

having a greater binding affinity for activins than for inhibins,

having substantially no binding affinity for transforming growth factors-ß, and

having substantially no binding affinity for non-activin-like proteins.

Presently preferred soluble, extracellular, ligand-binding proteins of the present invention typically comprise in the range of about 114-118 amino acids.

Especially preferred soluble, extracellular, ligand-binding proteins of the invention are those having substantially the same amino acid sequence as that set forth as:

residues 20-134 of Sequence ID No. 2;

residues 20-134 of Sequence ID No. 2, wherein the arginine residue at position number 39 is replaced by a lysine, and the isoleucine at residue number 92 is replaced by a valine; or

residues 21-132 of Sequence ID No. 4.

As employed herein, the term "substantially the same amino acid sequence" refers to amino acid sequences having at least about 80% identity with respect to the reference amino acid sequence, and will retain comparable functional and biological properties characteristic of the protein encoded by the reference amino acid. Preferably, proteins having "substantially the same amino acid sequence" will have at least about 90% amino acid identity with respect to the reference amino acid sequence; with greater than about 95% amino acid sequence identity being especially preferred.

The above-described soluble proteins can be employed for a variety of therapeutic uses, e.g., to block receptors of the invention from affecting processes which

the receptors would otherwise mediate. The presence of the soluble proteins of the invention will compete with functional ligand for the receptor, preventing the formation of a functional receptor-ligand complex, thereby blocking the normal regulatory action of the complex.

In accordance with yet another embodiment of the present invention, there are provided antibodies generated against the above-described soluble proteins and receptor proteins. Such antibodies can be employed for diagnostic applications, therapeutic applications, and the like. Preferably, for therapeutic applications, the antibodies employed will be monoclonal antibodies.

The above-described antibodies can be prepared employing standard techniques, as are well known to those of skill in the art, using the invention receptor proteins as antigens for antibody production.

In accordance with still another embodiment of the present invention, there are provided methods for modulating the transcription trans-activation of receptor(s) of the invention by contacting said receptor(s) with a modulating, effective amount of the above-described antibodies.

The soluble proteins of the invention, and the antibodies of the invention, can be administered to a subject employing standard methods, such as, for example, by intraperitoneal, intramuscular, intravenous, or subcutaneous injection, implant or transdermal modes of administration, and the like. In addition, methods such as transfection with viral or retroviral vectors encoding the invention compositions. One of skill in the art can readily determine dose forms, treatment regiments, etc, depending on the mode of administration employed.

In accordance with a further embodiment of the present invention, there are provided DNA sequences which encode the above-described soluble proteins and receptor proteins. Optionally, such DNA sequences, or fragments thereof, can be labeled with a readily detectable substituent (to be used, for example, as a hybridization probe).

The above-described receptor(s) can be encoded by numerous DNA sequences, e.g., a DNA sequence having a contiguous nucleotide sequence substantially the same as:

nucleotides 128 - 1609 of Sequence ID No. 1 (which encodes a mouse activin receptor);

variations of nucleotides 128 - 1609 of Sequence ID No. 1, wherein the codon for residue number 39 of the encoded amino acid codes for lysine, the codon for residue number 92 of the encoded amino acid codes for valine, and the codon for residue number 288 of the encoded amino acid encodes glutamine (which encodes a human activin receptor);

nucleotides 528 - 1997 of Sequence ID No. 3 (which encodes a Xenopus activin receptor); or

variations of any of the above sequences which encode the same amino acid sequences, but employ different codons for some of the amino acids.

As employed herein, the term "substantially the same as" refers to DNA having at least about 70% homology with respect to the nucleotide sequence of the DNA fragment with which subject DNA is being compared. Preferably, DNA "substantially the same as" a comparative DNA will be at least about 80% homologous to the comparative nucleotide sequence; with greater than about 90% homology being especially preferred.

Another DNA which encodes a receptor of the invention is one having a contiguous nucleotide sequence

substantially the same as:

nucleotides 71 - 1609 of Sequence ID No. 1 (which encodes a precursor-form of a mouse activin receptor);

variations of nucleotides 71 - 1609 of Sequence ID No. 1, wherein the codon for residue number 39 of the encoded amino acid codes for lysine, the codon for residue number 92 of the encoded amino acid codes for valine, and the codon for residue number 288 of the encoded amino acid encodes glutamine (which encodes a precursor-form of a human activin receptor);

nucleotides 468 - 1997 of Sequence ID No. 3 (which encodes a precursor form of a Xenopus activin receptor); or

variations of any of the above sequences which encode the same amino acid sequences, but employ different codons for some of the amino acids.

Yet another DNA which encodes the above-described receptor is one having a contiguous nucleotide sequence substantially the same as set forth in Sequence ID No. 1, Sequence ID No. 1' or Sequence ID No. 3.

In accordance with a further embodiment of the present invention, the receptor-encoding cDNAs can be employed to probe library(ies) (e.g., cDNA, genomic, and the like) for additional sequences encoding novel receptors of the activin/TGF-β superfamily. Such screening is initially carried out under low-stringency conditions, which comprise a temperature of less than about 42°C, a formamide concentration of less than about 50%, and a moderate to low salt concentration. Presently preferred conditions for such screening comprise a temperature of about 37°C, a formamide concentration of about 20%, and a salt concentration of about 5X standard saline citrate (SSC; 20X SSC contains 3M sodium chloride, 0.3M sodium citrate, pH 7.0). Such conditions will allow the identification of sequences which have a substantial degree

of similarity with the probe sequence, without requiring perfect homology for the identification of a stable hybrid. The phrase "substantial similarity" refers to sequences which share at least 50% homology. Preferably, hybridization conditions will be selected which allow the identification of sequences having at least 70% homology with the probe, while discriminating against sequences which have a lower degree of homology with the probe.

In accordance with yet another embodiment of the present invention, there is provided a method for the recombinant production of receptor(s) of the invention by expressing the above-described DNA sequences in suitable host cells.

The use of a wide variety of recombinant organisms has been described for the production of peptides. One of skill in the art can readily determine suitable hosts (and expression conditions) for use in the recombinant production of the peptides of the present invention. Yeast hosts, bacterial hosts, mammalian hosts, and the like can be employed. Regulatory sequences capable of controlling the expresseion of invention peptides are well known for each of these host systems, as are growth conditions under which expression occurs.

In accordance with a further embodiment of the present invention, there is provided a binding assay employing receptors of the invention, whereby a large number of compounds can be rapidly screened to determine which compounds, if any, are capable of binding to the receptors of the invention. Then, more detailed assays can be carried out with those compounds found to bind, to further determine whether such compounds act as agonists or antagonists of invention receptors.

Another application of the binding assay of the invention is the assay of test samples (e.g., biological fluids) for the presence or absence of members of the activin/TGF-ß superfamily of polypeptide growth factors. Thus, for example, serum from a patient displaying symptoms related to pathway(s) mediated by members of the activin/TGF-ß superfamily of polypeptide growth factors can be assayed to determine if the observed symptoms are perhaps caused by over- or under-production of such polypeptide growth factor.

The binding assays contemplated by the present invention can be carried out in a variety of ways, as can readily be identified by one of skill in the art. For example, competitive binding assays can be employed, as well as radioimmunoassays, ELISA, ERMA, and the like.

In accordance with a still further embodiment of the present invention, there are provided bioassays for evaluating whether test compounds are capable of acting as agonists or antagonists of receptor(s) of the present invention.

The bioassays of the present invention involve evaluating whether test compounds are capable of acting as either agonists or antagonists for members of the invention superfamily of receptors, or functional modified forms of said receptor protein(s). The bioassay for evaluating whether test compounds are capable of acting as agonists comprises:

(a) culturing cells containing:

DNA which expresses said receptor protein(s) or functional modified forms of said receptor protein(s), and

DNA encoding a hormone response element operatively linked to a reporter gene;

wherein said culturing is carried out in the

presence of at least one compound whose ability to induce transcription activation activity of receptor protein is sought to be determined, and thereafter

(b) monitoring said cells for expression of the product of said reporter gene.

The bioassay for evaluating whether test compounds are capable of acting as antagonists for receptor(s) of the invention, or functional modified forms of said receptor(s), comprises:

(a) culturing cells containing:

DNA which expresses said receptor protein(s), or functional modified forms of said receptor protein(s), and

DNA encoding a hormone response element operatively linked to a reporter gene

wherein said culturing is carried out in the presence of:

increasing concentrations of at least one compound whose ability to inhibit transcription activation of said receptor protein(s) is sought to be determined, and

a fixed concentration of at least one agonist for said receptor protein(s), or functional modified forms of said receptor protein(s); and thereafter

(b) monitoring in said cells the level of expression of the product of said reporter gene as a function of the concentration of said compound, thereby indicating the ability of said compound to inhibit activation of transcription.

Host cells contemplated for use in the bioassay(s) of the present invention, include CV-1 cells, COS cells, and the like; reporter and expression plasmids employed typically also contain the origin of replication

of SV-40; and the reporter and expression plasmids employed also typically contain a selectable marker.

The hormone response element employed in the bioassay(s) of the present invention can be selected from, for example, mouse mammary tumor virus long terminal repeat (MTV LTR), mammalian growth hormone promoter, and the reporter gene can be selected from chloramphenicol acetytransferase (CAT), luciferase, ß-galactosidase, and the like.

The cells can be monitored for the level of expression of the reporter gene in a variety of ways, such as, for example, by photometric means [e.g., by colorimetry (with a colored reporter product such as ß-galactosidase), by fluorescence (with a reporter product such as luciferase), etc], by enzyme activity, and the like.

Compounds contemplated for screening in accordance with the invention bioassays include activin- or TGF-β-like compounds, as well as compounds which bear no particular structural or biological relatedness to activin or TGF-β.

As employed herein, the phrase "activin- or TGF-β-like compounds" includes substances which have a substantial degree of homology (at least 20% homology) with the amino acid sequences of naturally occurring mammalian inhibin alpha and β_A or β_B chains (either singly or in any combination) as well as alleles, fragments, homologs or derivatives thereof which have substantially the same qualitative biological activity as mammalian inhibin, activin, or TGF-β. Examples of activin- or TGF-β-like compounds include activin A (a homodimer of two inhibin $ß_A$ subunits), activin B (a homodimer of two inhibin $ß_B$ subunits), activin AB (a heterodimer composed of one inhibin $ß_A$ subunit and one inhibin $ß_B$ subunit), inhibin A

(composed of the inhibin α subunit and an inhibin β_A subunit), inhibin B (composed of the inhibin α subunit and an inhibin β_B subunit), TGF-ß1 (a homodimer of two TGF-ß1 subunits), TGF-ß2 (a homodimer of two TGF-ß2 subunits), TGF-ß3 (a homodimer of two TGF-ß3 subunits), TGF-ß4 (a homodimer of two TGF-ß4 subunits), TGF-ß5 (a homodimer of two TGF-ß5 subunits), TGF-ß1.2 (a heterodimer of one TGF-ß1 subunit and one TGF-ß2 subunit), and the like.

Examples of compounds which bear no particular structural or biological relatedness to activin or TGF-β, but which are contemplated for screening in accordance with the bioassays of the present invention, include any compound that is capable of either blocking the action of the invention receptor peptides, or promoting the action of the invention receptor peptides, such as, for example, alkaloids and other heterocyclic organic compounds, and the like.

The method employed for cloning the receptor(s) of the present invention involves expressing, in mammalian cells, a cDNA library of any cell type thought to respond to members of the activin/TGF-ß superfamily of polypeptide growth factors (e.g., pituitary cells, placental cells, fibroblast cells, and the like). Then, the ability of the resulting mammalian cells to bind a labeled receptor ligand (i.e., a labeled member of the activin/TGF-ß superfamily of polypeptide growth factors) is determined. Finally, the desired cDNA insert(s) are recovered, based on the ability of that cDNA, when expressed in mammalian cells, to induce (or enhance) the binding of labeled receptor ligand to said cell.

In addition to the above-described applications of the receptor proteins and DNA sequences of the present invention, the receptor or receptor-encoding compositions of the invention can be used in a variety of ways. For

example, since activin is involved in many biological processes, the activin receptor (or antibodies thereto) can be applied to the modulation of such biological processes. For example, the stimulation of FSH release by activin can either be enhanced (for example, by supplying the subject with increased amounts of the activin receptor, relative to the amount of endogenous receptor, e.g., by transfecting the subject with a tissue specific activin-encoding construct), or depressed (e.g., by administration to a subject of antibodies to the activin receptor, thereby preventing formation of activin-receptor complex, which would then act to stimulate the release of FSH). Thus, the compositions of the present invention can be applied to the control of fertility in humans, domesticated animals, and animals of commercial interest.

As another example, the effect of activin on mitosis of red and white blood cells can be modulated, for example, by administering to a subject (employing suitable means of administration) a modulating, effective amount of activin receptor (which would enhance the ability of activin present in the cell to modulate mitosis). Alternatively, one could administer to a subject an antibody to the activin receptor (or a portion thereof), which would reduce the effect of activin by blocking the normal interaction between activin and activin receptor.

As additional examples of the wide utility of the invention compositions, receptors and/or antibodies of the invention can be used in such areas as the diagnosis and/or treatment of activin-dependent tumors, enhancing the survival of brain neurons, inducing abortion in livestock and other domesticated animals, inducing twinning in livestock and other domesticated animals, and so on.

As still further examples of the wide utility of the invention compositions, agonists identified for TGF-ß

specific receptors can be used to stimulate wound healing, to suppress the growth of TGF-ß-sensitive tumors, to suppress immune response (and thereby prevent rejection of transplanted organs), and the like. Antagonists or the soluble, ligand-binding domain derived from TGF-ß receptors can be used to block endogenous TGF-ß, thereby promoting liver regeneration and stimulating some immune responses.

It can be readily seen, therefore, that the invention compositions have utility in a wide variety of diagnostic, clinical, veterinary and research applications.

The invention will now be described in greater detail by reference to the following non-limiting examples.

EXAMPLES

Recombinant human (rh) activin A, rh activin B, and rh inhibin A were generously provided by Genentech, Inc. Porcine TGF-ß1 was obtained from R+D Systems.

Double-stranded DNA was sequenced by the dideoxy chain termination method using the Sequenase reagents from US Biochemicals. Comparison of DNA sequences to databases was performed using the FASTA program [Pearson and Lipman, Proc. Natl. Acad. Sci. USA 85: 2444-2448 (1988)].

EXAMPLE I

Construction and Subdivision of cDNA Library

Polyadenylated RNA was prepared from AtT20 cells using the Fast Track reagents from InVitrogen. cDNA was commercially synthesized and ligated into the plasmid vector pcDNA1 using non-palindromic BstXI linkers, yielding a library of approximately $5x10^6$ primary recombinants. The unamplified cDNA library was plated at 1000 clones per 100 mm plate, then scraped off the plates, frozen in glycerol

and stored at -70°.

Activin suppresses adrenocorticotrophic hormone (ACTH) secretion by both primary anterior pituitary cell cultures [Vale et al., Nature 321: 776-779 (1986)] and AtT20 mouse corticotropic cells. Because AtT20 cells possess activin receptors indistinguishable from those on other cell types (based on binding affinity measurements with activin A), these cells were chosen to be the source of cDNA for transfection. A cDNA library of approximately $5x10^6$ independent clones from AtT20 cells was constructed in the mammalian expression vector, pcDNA1, and screened using an expression cloning approach [Gearing et al., EMBO J. 8, 3667-3676 (1989)] based on the ability to detect activin binding to single transfected cells. The library was divided into pools of 1000 clones, DNA was prepared from each pool of clones and transiently transfected into COS cells, and the cells screened for the capacity to bind iodinated activin A. Binding was assessed by performing the transfections and binding reactions directly on chambered microscope slides, then dipping the slides in photographic emulsion and analyzing them under a microscope. Cells which had been transfected with an activin receptor cDNA, and consequently bound radioactive activin, were covered with silver grains. DNA from pools of clones were analyzed either singly or in groups of three. Of 300 pools (approximately 300,000 clones) assayed in this manner, one group of three generated two positive cells when transfected into COS cells. The positive pool (#64) was identified by transfecting and analyzing DNA from each pool of 1000 singly, and then was further fractionated until a single clone (pmActR1) was purified which generated $>10^4$ positive cells after transfection (see Table 1).

Table 1

Purification of the activin receptor clone from the AtT20 library

Pool	Clones/pool	Positive cells/slide
62,63,64	3x1000	2
64	1000	1-3
64-51	400	4-10
64-51-R10;64-51-C13	20	25-40
pmActR1	1	$>10^4$

The total number of transfected cells capable of binding ^{125}I activin A in a field of $2x10^5$ COS cells was counted for pools of clones at each stage of the purification process.

pmActR1 contained a 1.7 kb insert, coding for a protein of 342 amino acids (Figure 3); however, it was incomplete on the 3' end, thus the last 17 amino acids were encoded by vector sequences. In order to obtain the entire sequence, the AtT20 library was rescreened by hybridization with the 1.6 kb SacI-PstI fragment (Figure 3). Screening $6x10^5$ colonies yielded one additional positive clone (pmActR2) which had a 2.6 kb insert and contained the entire coding sequence for the mouse activin receptor (Figure 3). The nucleic acid sequence and the deduced amino acid sequence of the insert in pmActR2 are set forth in Sequence ID No. 1.

EXAMPLE II

COS Cell Transfection

Aliquots of the frozen pools of clones were grown overnight in 3 ml cultures of terrific broth, and mini-prep DNA prepared from 1.5 ml using the alkaline lysis method [Maniatis et al. Molecular Cloning (Cold Spring Harbor Laboratory (1982)]. 1/10 of the DNA from a mini-prep (10

Ml of 100 Ml) was used for each transfection.

$2x10^5$ COS cells were plated on chambered microscope slides (1 chamber - Nunc) that had been coated with 20 μg/ml poly-D-lysine and allowed to attach for at least 3 hours. Cells were subjected to DEAE-Dextran mediated transfection as follows. 1.5 ml of serum-free Dulbecco's Modified Eagle's medium (DME) containing 100 mM chloroquine was added to the cells. DNA was precipitated in 200 ml DME/chloroquine containing 500 mg/ml DEAE-Dextran, then added to the cells. The cells were incubated at 37° for 4 hours, then the media was removed and the cells were treated with 10% DMSO in HEPES buffered saline for 2 minutes. Fresh media was added and the cells assayed 3 days later. For transfections with the purified clone, $2.5x10^6$ cells were transfected in 100 mm dishes with 5 μg purified DNA. The total transfection volume was 10 ml, and the DNA was precipitated in 400 μl.

EXAMPLE III

Binding Assay

Cells were washed 2x with HEPES buffered saline (HDB) containing 0.1% BSA, then incubated for 90 minutes at 22° in 0.5 ml HDB, 0.1% BSA containing $7x10^5$ cpm ^{125}I activin A (approximately 7 ng, 500 pM). The cells were then washed 3X with cold HDB, fixed for 15 minutes at 22° in 2.5% glutaraldehyde/HDB and washed 2X with HDB. The chambers were then peeled off the slides, and the slides dehydrated in 95% ethanol, dried under vacuum, dipped in NTB2 photographic emulsion (Kodak) and exposed in the dark at 4° for 3 days. Following development of the emulsion, the slides were dehydrated in 95% ethanol, stained with eosin and coverslipped with DPX mountiant (Electron Microscopy Sciences). The slides were analyzed under darkfield illumination using a Leitz microscope.

EXAMPLE IV

Subdivision of Positive Pool

Of 300 pools screened (each pool containing about 1000 cDNAs), one positive pool (#64), which produced two positive cells, was identified. Bacteria from the frozen stock of this positive pool (#64) were replated at approximately 400 clones per plate, replica plates were made, and DNA was prepared from each subpool and analyzed employing the binding assay described above. Several positive subpools were found, which generated from 4-10 positive cells per slide. The bacteria from the replica plate of one positive subpool were picked onto a grid, and DNA prepared from pools of clones representing all the rows and all the columns, as described by Wong [Science 228:810-815 (1985)]. The identification of one positive row and one positive column unambiguously identified a single clone, which when transfected yielded $>10^4$ positive cells/$2x10^5$ cells.

EXAMPLE V

Radioreceptor Assay

10^5 COS cells transfected with either pmActR1 or pmActR2, or 10^6 untransfected COS cells, were plated in 6 well dishes and allowed to grow overnight. The cells were washed 2X with HDB, 0.1% BSA, and incubated at 22° for 90 minutes in 0.5 ml HDB, 0.1% BSA containing 100,000 cpm (approximately 1 ng, 75 pM) ^{125}I activin A (5 μg activin A was iodinated by chloramine T oxidation to a specific activity of 50-90 μCi/μg; iodinated activin A was purified on a 0.7x20 cm G-25 column) and varying amounts of unlabeled competitor hormone. Following binding, the cells were washed 3X with cold HDB, solubilized in 0.5 ml 0.5 N NaOH, removed from the dish and radioactivity was measured in a gamma counter. Data presented in Figure 5 are expressed as % specific binding, where 100% specific

binding is the difference between binding in the absence of competitor and binding in the presence of a 100 fold molar excess of unlabeled activin A. Binding parameters were determined using the program LIGAND [Munson P.J. and Rodbard, D., Anal. Biochem. 107:220-259 (1980)].

EXAMPLE VI

Chemical Cross-linking

$2x10^6$ COS cells, or $5x10^6$ AtT20 cells, were washed 2x with HDB, scraped off the dish, incubated for 90 minutes at 22° under constant rotation in 0.5 ml HDB containing $7x10^5$ cpm (approximately 500 pM) ^{125}I activin A with or without 500 ng (37 nM) unlabeled activin A. Cells were diluted with 1 ml HDB, pelleted by centrifugation and resuspended in 0.5 ml HDB. Disuccinimidyl suberate (DSS; freshly dissolved in DMSO) was added to 500 μM, and the cells incubated at 0° for 30 minutes. The cross-linking was terminated by addition of 1 ml 50 mM Tris-HCl pH 7.5, 100 mM NaCl, then the cells were pelleted by centrifugation, resuspended in 100 μl 50 mM Tris-HCl pH 7.5, 1% Triton X-100 and incubated at 0° for 60 minutes. The samples were centrifuged 5 minutes at 13,000xg, and the Triton-soluble supernatants analyzed by SDS-PAGE using 8.5% polyacrylamide gels. The gels were dried and subjected to autoradiography for 4-14 days.

EXAMPLE VII

RNA Blot Analysis

Total RNA was purified from tissue culture cells and tissues using LiCl precipitation. 20 μg total RNA was run on 1.2% agarose, 2.2M formaldehyde gels, blotted onto nylon membranes (Hybond - NEN), and hybridized with a 0.6 kb KpnI fragment (see Figure 3) which had been labeled with ^{32}P by random priming using reagents from US Biochemicals. Hybridization was performed at 42° in 50% formamide, and

the filters were washed at 65° in 0.2X SSC.

EXAMPLE VIII

Sequence Analysis

Full length mouse activin receptor clone encodes a protein of 513 amino acids, with a 5' untranslated region of 70 bp and a 3' untranslated region of 951 bp. pmActR2 does not contain a poly A tail, although it does have a potential poladenylylation site at bp 2251. The insert in clone pmActR1 had an additional 551 bp of 5' untranslated sequence, was identical in the overlapping range, and stopped at the 3' end at base 1132 of pmActR2. The first methionine codon (ATG), at bp 71, in pmActR2 is in a favorable context for translation initiation [Kozak, M., Nucl. Acids Res. 15:8125-8148 (1987)], and is preceded by an in-frame stop codon. pmActR1 contains 3 additional ATGs in the 5' untranslated region; however, none of these is in an appropriate context for initiation, and all are followed by in-frame stop codons. While this unusually long 5' leader sequence may have functional significance, it is clearly not necessary for proper expression, because pmActR2, which lacks most of that sequence, can be functionally expressed in COS cells (see below).

Hydropathy analysis using the method of Kyte and Doolittle [J. Mol. Biol. 157:105-132 (1982)] revealed two hydrophobic regions: a 10 amino acid stretch at the amino terminus assumed to be a single peptide, and a single putative 26 residue membrane-spanning region between amino acids 119-142 (see Figure 1 and Sequence ID No. 2). The signal peptide contains the conserved n-, h- and c- domains common to signal sequences; the site of cleavage of the signal peptide, before Ala^{1}, is predicted based on rules described by von Heijne [Biochim. Biophys. Act. 947:307-333 (1988)]. As is common for the cytoplasmic side of membrane-spanning domains, the predicted transmembrane

region is closely followed by two basic amino acids. The mature mouse activin receptor is thus predicted to be a 494 amino acid type I membrane protein of Mr 54 kDa, with a 116 amino acid N-terminal extracellular ligand binding domain, and a 346 amino acid intracellular signalling domain.

Comparision of the activin receptor sequence to the sequence databases revealed structural similarity in the intracellular domain to a number of receptor and non-receptor kinases. Analysis of the sequences of all kinases has led to the identification of a 300 amino acid kinase domain characterized by 12 subdomains containing a number of highly conserved amino acids [Hanks, S.K. and Quinn, A.M., Meth. Enzymol. 200:38-62 (1991) and Hanks et al., Science 241:42-52 (1988)]; the activin receptor sequence has all of these conserved subdomains in the proper order (Figure 4). A conserved Gly in subdomain I is replaced by Ala^{180} in the activin receptor, but this residue has also been observed in other kinases. Based upon structural relatedness, therefore, this receptor is expected to be a functional protein kinase.

The sequences in two of these subdomains (VIB and VIII) can be used to predict tyrosine vs. serine/threonine substrate specificity [Hanks et al., (1988) supra]. The sequence of the mouse activin receptor in both of these subdomains is characteristic of serine kinases.

Table 2

Kinase Domain Predictive Sequences

Subdomain	VIB	SEQ ID NO.	VIII	SEQ ID NO.
serine kinase consensus	DLKPEN	5	G(T/S)XX(Y/F)X	6
activin receptor	DIKSKN	7	GTRRYM	8
tyrosine kinase consensus	DLAARN	9	XP(I/V)(K/R)W(T/M)	10

Therefore, the activin receptor is expected to have serine/threonine specificity. Furthermore, the activin receptor does not have a tyrosine residue in the standard autophosphorylation region between subdomains VII and VIII, indicating that it is not a standard tyrosine kinase. The receptor could potentially autophosphorylate at Ser^{333} or Thr^{337}. One interesting additional possibility is that the activin receptor kinase may have specificity for serine, threonine and tyrosine residues. Several kinases with these properties have recently been described [see, for example, Howell et al., Mol. Cell. Biol. 11:568-572 (1991), Stern et al., Mol. Cell. Biol. 11:987-1001 (1991) and Featherstond, C. and Russell, P., Nature 349:808-811 (1991)].

Phylogenetic analysis of the activin receptor compared to 161 other kinase sequences revealed that the activin receptor and the C.elegans protein, daf-1 [Georgi et al., Cell 61:635-645 (1990)] may constitute a separate subfamily of kinases (see Figure 6). daf-1 is a putative transmembrane receptor involved in the developmental arrest of a non-feeding larval state and shares 32% identity with the activin receptor (see Figure 6). Like the activin receptor, daf-1 is predicted to be a transmembrane serine/threonine-specific kinase; furthermore, both daf and the activin receptor have short, conserved inserts in the kinase domain sequence between subdomains VIA-VIB and X-XI that are not present in any other kinase (underlined in Figure 4B). This additional similarity lends credence to their belonging to a unique subfamily of kinases. The activin receptor is quite distantly related (18% amino acid sequence identity) to the only other known transmembrane serine/threonine protein kinase, encloded by the ZmPK gene of maize [Walker, J.C. and Zhang, R., Nature 345:743-746 (1990)].

The extracellular domain of the activin receptor did not show similarity to any other sequences in the databases. This ligand binding domain is relatively small in comparison to those found in other growth factor receptors, but like those receptors this domain has a high cysteine content. The pattern of these Cys residues, however, is not like either an immunoglobulin fold or the cysteine rich repeats of the EGF receptor. There are also two potential sites of N-linked glycosylation in the extracellular domain, as well as a number of potential phosphorylation sites for protein kinase C and casein kinase II in the intracellular domain.

EXAMPLE IX

Binding Properties of the Cloned Activin Receptor

To verify that the cloned receptor is activin specific, competition binding experiments were performed on COS cells transiently transfected with either pmActR1 or pmActR2. Cells transfected with either construct bound activin A with a single high affinity component (Kd = 180 pM; Figure 5), indicating that a functional (structurally complete) intracellular kinase domain is not required for ligand binding. This binding affinity is consistent with that measured on other activin-responsive cell types [see, for example, Campen, C.A. and Vale, W., Biochem. Biophys. Res. Comm. 157:844-849 (1988); Hino et al., J. Biol. Chem. 264:10309-10314 (1989); Sugino et al., J. Biol. Chem. 263: 15249-15252 (1988); and Kondo et al., Biochem. Biophys. Res. Comm, 161:1267-1272 (1989)]. Untransfected COS cells do not bind activin A. The transfected cultures as a whole expressed approximately 26,000 receptors per cell; however, because only 15% of the cells express the transfected gene (as measured by quantitating transfected cells as a fraction of all cells following dipping in emulsion), each transfected cell expressed an average of 175,000 receptors per cell. The

level of expression per cell varies considerably, though, based on the number of accumulated silver grains. This value is comparable to the expression of other transfected cell surface proteins in COS cells.

Binding of iodinated activin A to COS cells transiently transfected with pmActR2 could be competed by activin B with slightly reduced potency compared to activin A; by inhibin A with approximately 10-fold lower potency; and could not be competed by TGF-ß1 (Figure 5B). This affinity and specificity of binding match those observed following binding of activin A to a number of other activin-responsive cell types. Although activin B appears to bind the transfected receptor with lower affinity than activin A, the activin B preparation used in these experiments may have suffered a reduction in potency, based on a comparison of bioactivity with activin A, since the recombinant synthesis of the activin B employed herein had been carried out some time ago [recombinant synthesis of activin B is described by Mason et al., in Mol. Endocrinol. 3: 1352-1358 (1989)]. It is likely that this cDNA encodes a receptor for multiple forms of activin.

The size of the cloned activin receptor was analyzed by affinity cross-linking ^{125}I activin A to COS cells transfected with pmActR2 using the bifunctional chemical cross-linker, disuccinimidyl suberate (DSS). A major cross-linked band of 84 kDa was observed in transfected, but not in untransfected cells. Subtracting the molecular weight of activin, this represents a protein of 56 kDa, which corresponds well to the molecular weight predicted from the nucleic acid sequence data. Cross-linking ^{125}I activin A to AtT20 cells yields a major band of 65 kDa, with minor bands of approximately 78 and 84 kDa. The size of the largest band matches that generated by the cloned receptor. The smaller bands could be either separate proteins, different phosphorylated forms of the

same protein, or degradation products of the full length clone; the sequences DKKRR at amino acid 35 and KKKR at amino acid 416 could be potential sites of proteolysis. Alternatively, these bands could come from alternatively spliced products of the same gene.

The 84 and 65 kDa cross-linked bands have also been observed in other activin-responsive cell types [Hino, supra; Centrella et al., Mol. Cell. Biol. 11:250-258 (1991)], and interpreted to represent the signalling receptor, although complexes of other sizes have also been seen as well. The size of the activin receptor is very similar to a putative TGF-ß receptor, to the limited extent it has been characterized by chemical cross-linking [see Massague et al., Ann. N.Y. Acad. Sci. 593: 59-72 (1990)].

EXAMPLE X

Expression of Activin Receptor mRNA

The distribution of activin receptor mRNA was analyzed by Northern blot. Two mRNA species, of 6.0 and 3.0 kb, were observed in AtT20 cells as well as a number of mouse tissues, including brain, testis, pancreas, liver and kidney. The total combined size of the inserts from pmActR1 and pmActR2 is 3.1 kb, which corresponds to the size of the smaller transcript. Neither the extent of similarity between the two mRNAs, nor the significance of having two transcripts is clear. The genes for several other hormone receptors have been shown to be alternatively spliced to generate both a cell surface receptor and a soluble binding protein, and it is possible that the activin receptor is processed in a similar manner.

Interestingly, the relative abundance of the two transcripts varies depending on the source. While AtT20 cells have approximately equal levels of both mRNAs, most tissues had much greater levels of the 6.0 kb transcript,

with little or no expression of the 3.0 kb transcript. Testis, on the other hand, had a greater amount of the 3.0 kb band. Expression of activin receptor mRNA in brain, liver and testis is in accord with described biological actions of activin in those tissues [Mine et al., Endocrinol. 125:586-591 (1989); Vale et al., Peptide Growth Factors and Their Receptors, Handbook of Experimental Pharmacology, M.A. Sporn and A.B. Roberts, ed., Springer-Verlag (1990), in press].

EXAMPLE XI

Identification of a Human Activin Receptor

A human testis library (purchased from Clontech; catalog no. HL1010b) was probed with the full length mouse activin receptor gene (see Sequence ID No. 1) under the following conditions:

Hybridization stringency:

20% formamide, 6X SSC at 42°C;

Wash stringency:

2X SSC, 0.1% SDS at 42°C.

A sequence which is highly homologous with the mouse activin receptor was identified (Sequence ID No. 1'). Due to the high degree of homology between this receptor and the mouse activin receptor, this receptor is designated as the human form of the activin receptor from the same subclass as the mouse receptor described above.

EXAMPLE XII

Identification of a Xenopus Activin Receptor

A Xenopus stage 17 embryo cDNA library (prepared as described by Kintner and Melton in Development 99: 311-325 (1987) was probed with the full length mouse activin receptor gene (see Sequence ID No. 1) under the following conditions:

Hybridization stringency:

20% formamide, 6X SSC at 42°C;

Wash stringency:

2X SSC, 0.1% SDS at 42°C.

A sequence having a substantial degree of homology with respect to the mouse activin receptor was identified (Sequence ID No. 3). The degree of overall amino acid homology (relative to the mouse acitvin receptor) is only about 69% (with 77% homology in the intracellular domain and 58% homology in the extracellular domain). Due to the moderate degree of homology between this receptor and the mouse activin receptor, this receptor is designated as an activin receptor from a different subclass than the mouse receptor described above.

EXAMPLE XIII

Functional Assays of ActRs in Xenopus embryos

To determine whether xActRIIB can transmit a signal in response to activin, xActRIIB RNA was synthesized in vitro and injected into *Xenopus* embryos at two different concentrations. Injected embryos were allowed to develop to stage 9, at which time animal caps were dissected and treated overnight with different concentrations of activin. The xActRIIB cDNA was cloned into rp64T [see Krieg and Melton in Methods in Enzymology, Abelson and Simon, Eds. (Academic Press, New York, 1987), vol. 155, p. 397] and transcribed in vitro to generate a capped, synthetic xActRIIB RNA [see Melton et al., in Nucleic Acids Res. 12:7035 (1984) and Kintner in Neuron 1:545 (1988)]. Embryos at the two- to four-cell stage were injected with about 20 nl of RNA at concentrations of 0.02 ng/nl, or 0.1 ng/nl, spread between four quadrants of the animal pole. At stage 9, animal caps were removed from RNA-injected embryos and incubated in 0.5x modified mammalian Ringer's (MMR), 0.1% bovine serum albumin (BSA) with different

concentrations of purified, porcine activin A (six caps per incubation). After 20 hours in culture, total RNA was prepared.

The response of the caps to activin was assessed by quantifying muscle-specific actin RNA with a ribonuclease protection assay as per Blackwell and Weintraub, Science 250:1104 (1990). Embryos injected with 0.4 and 2.0 ng of xActRIIB RNA were approximately 10- and 100-fold more sensitive, respectively, to activin than control embryos. The low amount of muscle actin found in animal caps in the absence of added activin A is probably a consequence of contamination of the animal cap with a small amount of marginal zone tissue.

The amount of muscle actin decreased with increasing concentration of activin in the embryos injected with 2 ng of xActRIIB RNA. This is consistent with the observation that—isolated—animal cap cells uniformly exposed to different concentrations of activin only form muscle cells in response to a narrow range of activin concentrations [see Blackmann and Kadesch in Genes and Development 5:1057 (1990)]. The present results indicate that the concentration of ligand and the amount of receptor are both important in determining the signal transmitted. Thus, the range of activin concentrations that lead to muscle differentiation is lower in animal cap cells from injected embryos, which are expressing more receptor than normal, than from uninjected embryos.

EXAMPLE XIV

Analysis of kinase activity of mActRII

A fragment of cDNA corresponding to the entire intracellular domain of mActRII (amino acids 143-494) was subcloned into the vector pGEX-2T [see Smith and Johnson in Gene 67:31-40 (1988)], creating a fusion protein between

glutathione S-transferase (GST) and the putative kinase domain of the receptor. This plasmid was introduced into bacteria and the expressed fusion protein was purified using glutathione affinity chromatography as described by Smith and Johnson. Approximately 100-200 ng of fusion protein, or of purified GST, were incubated with 25 μCi [γ-^{32}P] ATPin a buffer containing 50 mM Tris, 10 mM $MgCl_2$ for 30 minutes at 37°C. The products were analyzed by SDS-PAGE and autoradiography. The fusion protein, but not the GST alone, became phosphorylated, indicating that the kinase domain of the fusion protein was functional. Phosphoamino acid analysis, performed according to Cooper et al. [Meth. Enzym. 99:387 (1983)], indicated that the predominant amino acid residue that became phosphorylated was threonine.

While the invention has been described in detail with reference to certain preferred embodiments thereof, it will be understood that modifications and variations are within the spirit and scope of that which is described and claimed.

SUMMARY OF SEQUENCES

Sequence ID No. 1 is the nucleic acid sequence (and the deduced amino acid sequence) of a cDNA encoding a mouse-derived activin receptor of the present invention.

Sequence ID No. 1' is a nucleic acid sequence encoding a human-derived activin receptor of the present invention. Sequence ID No. 1' is substantially the same as Sequence ID No. 1, except that the codon for amino acid residue number 39 encodes lysine (i.e., nucleotides 185-187 are AAA or AAG), the codon for amino acid residue 92 encodes valine (i.e., nucleotides 344-346 are GTN, wherein N is A, C, G or T), and the codon for amino acid residue number 288 encodes glutamine (i.e., nucleotides 932-934 are CAA or CAG).

Sequence ID No. 2 is the deduced amino acid sequence of a mouse-derived activin receptor of the present invention.

Sequence ID No. 2' is an amino acid sequence for a human-derived activin receptor of the present invention. Sequence ID No. 2' is substantially the same as Sequence ID No. 2, except that amino acid residue number 39 is lysine, amino acid residue 92 is valine, and amino acid residue number 288 is glutamine.

Sequence ID No. 3 is the nucleic acid sequence (and the deduced amino acid sequence) of a cDNA encoding a Xenopus-derived activin receptor of the present invention.

Sequence ID No. 4 is the deduced amino acid sequence of a Xenopus-derived activin receptor of the present invention.

Sequence ID No. 5 is the amino acid sequence of the VIB subdomain of the serine kinase consensus sequence.

Sequence ID No. 6 is the amino acid sequence of the VIII subdomain of the serine kinase consensus sequence.

Sequence ID No. 7 is the amino acid sequence of the VIB subdomain of the invention activin receptor.

Sequence ID No. 8 is the amino acid sequence of the VIII subdomain of the invention activin receptor.

Sequence ID No. 9 is the amino acid sequence of the VIB subdomain of the tyrosine kinase consensus sequence.

Sequence ID No. 10 is the amino acid sequence of the VIII subdomain of the tyrosine kinase consensus sequence.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

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(ii) TITLE OF INVENTION: CLONING AND RECOMBINANT PRODUCTION OF RECEPTOR(S) OF THE ACTIVIN/TGF-BETA SUPERFAMILY

(iii) NUMBER OF SEQUENCES: 10

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(A) MEDIUM TYPE: Floppy disk
(B) COMPUTER: IBM PC compatible
(C) OPERATING SYSTEM: PC-DOS/MS-DOS
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25

(vi) CURRENT APPLICATION DATA:
(A) APPLICATION NUMBER: US
(B) FILING DATE: 08-MAY-1992
(C) CLASSIFICATION:

(viii) ATTORNEY/AGENT INFORMATION:
(A) NAME: Reiter, Mr., Stephen E.
(B) REGISTRATION NUMBER: 31192
(C) REFERENCE/DOCKET NUMBER: P31 9309/FP31 9291

(ix) TELECOMMUNICATION INFORMATION:
(A) TELEPHONE: (619) 546-4737
(B) TELEFAX: (619) 546-9392

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 2563 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 71..1609

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

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CTCCGAGGAA GACCCAGGGA ACTGGATATC TAGCGAGAAC TTCCTACGGC TTCTCCGGCG      60

CCTCGGGAAA ATG GGA GCT GCT GCA AAG TTG GCG TTC GCC GTC TTT CTT      109
           Met Gly Ala Ala Ala Lys Leu Ala Phe Ala Val Phe Leu
             1               5                  10
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ATC TCT TGC TCT TCA GGT GCT ATA CTT GGC AGA TCA GAA ACT CAG GAG          157
Ile Ser Cys Ser Ser Gly Ala Ile Leu Gly Arg Ser Glu Thr Gln Glu
     15                  20                  25

TGT CTT TTC TTT AAT GCT AAT TGG GAA AGA GAC AGA ACC AAC CAG ACT          205
Cys Leu Phe Phe Asn Ala Asn Trp Glu Arg Asp Arg Thr Asn Gln Thr
 30                  35                  40                  45

GGT GTT GAA CCT TGC TAT GGT GAT AAA GAT AAA CGG CGA CAT TGT TTT          253
Gly Val Glu Pro Cys Tyr Gly Asp Lys Asp Lys Arg Arg His Cys Phe
                 50                  55                  60

GCT ACC TGG AAG AAT ATT TCT GGT TCC ATT GAA ATA GTG AAG CAA GGT          301
Ala Thr Trp Lys Asn Ile Ser Gly Ser Ile Glu Ile Val Lys Gln Gly
            65                  70                  75

TGT TGG CTG GAT GAT ATC AAC TGC TAT GAC AGG ACT GAT TGT ATA GAA          349
Cys Trp Leu Asp Asp Ile Asn Cys Tyr Asp Arg Thr Asp Cys Ile Glu
        80                  85                  90

AAA AAA GAC AGC CCT GAA GTG TAC TTT TGT TGC TGT GAG GGC AAT ATG          397
Lys Lys Asp Ser Pro Glu Val Tyr Phe Cys Cys Cys Glu Gly Asn Met
     95                  100                 105

TGT AAT GAA AAG TTC TCT TAT TTT CCG GAG ATG GAA GTC ACA CAG CCC          445
Cys Asn Glu Lys Phe Ser Tyr Phe Pro Glu Met Glu Val Thr Gln Pro
110                 115                 120                 125

ACT TCA AAT CCT GTT ACA CCG AAG CCA CCC TAT TAC AAC ATT CTG CTG          493
Thr Ser Asn Pro Val Thr Pro Lys Pro Pro Tyr Tyr Asn Ile Leu Leu
                130                 135                 140

TAT TCC TTG GTA CCA CTA ATG TTA ATT GCA GGA ATT GTC ATT TGT GCA          541
Tyr Ser Leu Val Pro Leu Met Leu Ile Ala Gly Ile Val Ile Cys Ala
            145                 150                 155

TTT TGG GTG TAC AGA CAT CAC AAG ATG GCC TAC CCT CCT GTA CTT GTT          589
Phe Trp Val Tyr Arg His His Lys Met Ala Tyr Pro Pro Val Leu Val
        160                 165                 170

CCT ACT CAA GAC CCA GGA CCA CCC CCA CCT TCC CCA TTA CTA GGG TTG          637
Pro Thr Gln Asp Pro Gly Pro Pro Pro Pro Ser Pro Leu Leu Gly Leu
    175                 180                 185

AAG CCA TTG CAG CTG TTA GAA GTG AAA GCA AGG GGA AGA TTT GGT TGT          685
Lys Pro Leu Gln Leu Leu Glu Val Lys Ala Arg Gly Arg Phe Gly Cys
190                 195                 200                 205

GTC TGG AAA GCC CAG TTG CTC AAT GAA TAT GTG GCT GTC AAA ATA TTT          733
Val Trp Lys Ala Gln Leu Leu Asn Glu Tyr Val Ala Val Lys Ile Phe
                210                 215                 220

CCA ATA CAG GAC AAA CAG TCC TGG CAG AAT GAA TAT GAA GTC TAT AGT          781
Pro Ile Gln Asp Lys Gln Ser Trp Gln Asn Glu Tyr Glu Val Tyr Ser
            225                 230                 235

CTA CCT GGA ATG AAG CAT GAG AAC ATA CTA CAG TTC ATT GGT GCA GAG          829
Leu Pro Gly Met Lys His Glu Asn Ile Leu Gln Phe Ile Gly Ala Glu
        240                 245                 250

AAA AGA GGC ACC AGT GTG GAT GTG GAC CTG TGG CTA ATC ACA GCA TTT          877
Lys Arg Gly Thr Ser Val Asp Val Asp Leu Trp Leu Ile Thr Ala Phe
    255                 260                 265

CAT GAA AAG GGC TCA CTG TCA GAC TTT CTT AAG GCT AAT GTG GTC TCT          925
His Glu Lys Gly Ser Leu Ser Asp Phe Leu Lys Ala Asn Val Val Ser
270                 275                 280                 285
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TGG AAT GAA CTT TGT CAT ATT GCA GAA ACC ATG GCT AGA GGA TTG GCA          973
Trp Asn Glu Leu Cys His Ile Ala Glu Thr Met Ala Arg Gly Leu Ala
                290                 295                 300

TAT TTA CAT GAG GAT ATA CCT GGC TTA AAA GAT GGC CAC AAG CCT GCA         1021
Tyr Leu His Glu Asp Ile Pro Gly Leu Lys Asp Gly His Lys Pro Ala
            305                 310                 315

ATC TCT CAC AGG GAC ATC AAA AGT AAA AAT GTG CTG TTG AAA AAC AAT         1069
Ile Ser His Arg Asp Ile Lys Ser Lys Asn Val Leu Leu Lys Asn Asn
        320                 325                 330

CTG ACA GCT TGC ATT GCT GAC TTT GGG TTG GCC TTA AAG TTC GAG GCT         1117
Leu Thr Ala Cys Ile Ala Asp Phe Gly Leu Ala Leu Lys Phe Glu Ala
    335                 340                 345

GGC AAG TCT GCA GGT GAC ACC CAT GGG CAG GTT GGT ACC CGG AGG TAT         1165
Gly Lys Ser Ala Gly Asp Thr His Gly Gln Val Gly Thr Arg Arg Tyr
350                 355                 360                 365

ATG GCT CCA GAG GTG TTG GAG GGT GCT ATA AAC TTC CAA AGG GAC GCA         1213
Met Ala Pro Glu Val Leu Glu Gly Ala Ile Asn Phe Gln Arg Asp Ala
                370                 375                 380

TTT CTG AGG ATA GAT ATG TAC GCC ATG GGA TTA GTC CTA TGG GAA TTG         1261
Phe Leu Arg Ile Asp Met Tyr Ala Met Gly Leu Val Leu Trp Glu Leu
            385                 390                 395

GCT TCT CGT TGC ACT GCT GCA GAT GGA CCC GTA GAT GAG TAC ATG TTA         1309
Ala Ser Arg Cys Thr Ala Ala Asp Gly Pro Val Asp Glu Tyr Met Leu
        400                 405                 410

CCA TTT GAG GAA GAA ATT GGC CAG CAT CCA TCT CTT GAA GAT ATG CAG         1357
Pro Phe Glu Glu Glu Ile Gly Gln His Pro Ser Leu Glu Asp Met Gln
    415                 420                 425

GAA GTT GTT GTG CAT AAA AAA AAG AGG CCT GTT TTA AGA GAT TAT TGG         1405
Glu Val Val Val His Lys Lys Lys Arg Pro Val Leu Arg Asp Tyr Trp
430                 435                 440                 445

CAG AAA CAT GCA GGA ATG GCA ATG CTC TGT GAA ACG ATA GAA GAA TGT         1453
Gln Lys His Ala Gly Met Ala Met Leu Cys Glu Thr Ile Glu Glu Cys
                450                 455                 460

TGG GAT CAT GAT GCA GAA GCC AGG TTA TCA GCT GGA TGT GTA GGT GAA         1501
Trp Asp His Asp Ala Glu Ala Arg Leu Ser Ala Gly Cys Val Gly Glu
            465                 470                 475

AGA ATT ACT CAG ATG CAA AGA CTA ACA AAT ATC ATT ACT ACA GAG GAC         1549
Arg Ile Thr Gln Met Gln Arg Leu Thr Asn Ile Ile Thr Thr Glu Asp
        480                 485                 490

ATT GTA ACA GTG GTC ACA ATG GTG ACA AAT GTT GAC TTT CCT CCC AAA         1597
Ile Val Thr Val Val Thr Met Val Thr Asn Val Asp Phe Pro Pro Lys
    495                 500                 505

GAA TCT AGT CTA TGATGGTGGC ACCGTCTGTA CACACTGAGG ACTGGGACTC             1649
Glu Ser Ser Leu
510

TGAACTGGAG CTGCTAAGCT AAGGAAAGTG CTTAGTTGAT TTTCTGTGTG AAATGAGTAG       1709

GATGCCTCCA GGACATGTAC GCAAGCAGCC CCTTGTGGAA AGCATGGATC TGGGAGATGG       1769

ATCTGGGAAA CTTACTGCAT CGTCTGCAGC ACAGATATGA AGAGGAGTCT AAGGGAAAAG       1829

CTGCAAACTG TAAAGAACTT CTGAAAATGT ACTCGAAGAA TGTGGCCCTC TCCAAATCAA       1889
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GGATCTTTTG GACCTGGCTA ATCAAGTATT TGCAAAACTG ACATCAGATT TCTTAATGTC 1949

TGTCAGAAGA CACTAATTCC TTAAATGAAC TACTGCTATT TTTTTTAAAT GAAAAACTTT 2009

TCATTTCAGA TTTTAAAAAG GGTAACTTTT TATTGCATTT GCTGTTGTTT CTATAAATGA 2069

CTATTGTAAT GCCAACATGA CACAGCTTGT GAATGTGTAG TGTGCTGCTG TTCTGTGTAC 2129

ATAGTCATCA AAGTGGGGTA CAGTAAAGAG GCTTCCAAGC ATTACTTTAA CCTCCCTCAA 2189

CAAGGTATAC CTCAGTTCCA CGGTTGTTAA ATTATAAAAT TGAAAACACT AACAGAATTT 2249

GAATAAATCA GTCCATGTTT TATAACAAGG TTAATTACAA ATTCACTGTG TTATTTAAGA 2309

AAAAATGGTA AGCTATGCTT AGTGCCAATA GTAAGTGGCT ATTTGTAAAG CAGTGTTTTA 2369

GCTTTTCTTC TACTGGCTTG TAATTTAGGG AAAACAAGTG CTGTCTTTGA AATGGAAAAG 2429

AATATGGTGT CACCCTACCC CCCATACTTA TATCAAGGTC CCAAAATATT CTTTTCCATT 2489

TCAAAGACAG CACTTTGAAA ACCCTAAATT ACAAGCCAGT AGAAGAAAAG CTAAAACACG 2549

CTTTACAAAT AGCC 2563

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 513 amino acids
(B) TYPE: amino acid
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Gly Ala Ala Ala Lys Leu Ala Phe Ala Val Phe Leu Ile Ser Cys
1 5 10 15

Ser Ser Gly Ala Ile Leu Gly Arg Ser Glu Thr Gln Glu Cys Leu Phe
20 25 30

Phe Asn Ala Asn Trp Glu Arg Asp Arg Thr Asn Gln Thr Gly Val Glu
35 40 45

Pro Cys Tyr Gly Asp Lys Asp Lys Arg Arg His Cys Phe Ala Thr Trp
50 55 60

Lys Asn Ile Ser Gly Ser Ile Glu Ile Val Lys Gln Gly Cys Trp Leu
65 70 75 80

Asp Asp Ile Asn Cys Tyr Asp Arg Thr Asp Cys Ile Glu Lys Lys Asp
85 90 95

Ser Pro Glu Val Tyr Phe Cys Cys Cys Glu Gly Asn Met Cys Asn Glu
100 105 110

Lys Phe Ser Tyr Phe Pro Glu Met Glu Val Thr Gln Pro Thr Ser Asn
115 120 125

Pro Val Thr Pro Lys Pro Pro Tyr Tyr Asn Ile Leu Leu Tyr Ser Leu
130 135 140

Val Pro Leu Met Leu Ile Ala Gly Ile Val Ile Cys Ala Phe Trp Val
145 150 155 160

Tyr Arg His His Lys Met Ala Tyr Pro Pro Val Leu Val Pro Thr Gln
165 170 175

Asp Pro Gly Pro Pro Pro Pro Ser Pro Leu Leu Gly Leu Lys Pro Leu
180 185 190

Gln Leu Leu Glu Val Lys Ala Arg Gly Arg Phe Gly Cys Val Trp Lys
195 200 205

Ala Gln Leu Leu Asn Glu Tyr Val Ala Val Lys Ile Phe Pro Ile Gln
210 215 220

Asp Lys Gln Ser Trp Gln Asn Glu Tyr Glu Val Tyr Ser Leu Pro Gly
225 230 235 240

Met Lys His Glu Asn Ile Leu Gln Phe Ile Gly Ala Glu Lys Arg Gly
245 250 255

Thr Ser Val Asp Val Asp Leu Trp Leu Ile Thr Ala Phe His Glu Lys
260 265 270

Gly Ser Leu Ser Asp Phe Leu Lys Ala Asn Val Val Ser Trp Asn Glu
275 280 285

Leu Cys His Ile Ala Glu Thr Met Ala Arg Gly Leu Ala Tyr Leu His
290 295 300

Glu Asp Ile Pro Gly Leu Lys Asp Gly His Lys Pro Ala Ile Ser His
305 310 315 320

Arg Asp Ile Lys Ser Lys Asn Val Leu Leu Lys Asn Asn Leu Thr Ala
325 330 335

Cys Ile Ala Asp Phe Gly Leu Ala Leu Lys Phe Glu Ala Gly Lys Ser
340 345 350

Ala Gly Asp Thr His Gly Gln Val Gly Thr Arg Arg Tyr Met Ala Pro
355 360 365

Glu Val Leu Glu Gly Ala Ile Asn Phe Gln Arg Asp Ala Phe Leu Arg
370 375 380

Ile Asp Met Tyr Ala Met Gly Leu Val Leu Trp Glu Leu Ala Ser Arg
385 390 395 400

Cys Thr Ala Ala Asp Gly Pro Val Asp Glu Tyr Met Leu Pro Phe Glu
405 410 415

Glu Glu Ile Gly Gln His Pro Ser Leu Glu Asp Met Gln Glu Val Val
420 425 430

Val His Lys Lys Lys Arg Pro Val Leu Arg Asp Tyr Trp Gln Lys His
435 440 445

Ala Gly Met Ala Met Leu Cys Glu Thr Ile Glu Glu Cys Trp Asp His
450 455 460

Asp Ala Glu Ala Arg Leu Ser Ala Gly Cys Val Gly Glu Arg Ile Thr
465 470 475 480

Gln Met Gln Arg Leu Thr Asn Ile Ile Thr Thr Glu Asp Ile Val Thr
485 490 495

Val Val Thr Met Val Thr Asn Val Asp Phe Pro Pro Lys Glu Ser Ser
500 505 510

Leu

(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 2335 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: cDNA

(vii) IMMEDIATE SOURCE:
(B) CLONE: XACTR

(ix) FEATURE:
(A) NAME/KEY: CDS
(B) LOCATION: 468..1997

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

```
CCGCCCACAC AGTGCAGTGA ATAATAGCCG GTGCGGCCCC TCCCCTCTTT CCCTGGCAGT      60

TGTGTATCTG TCACATTGAA GTTTGGGCTC CTGTGAGTCT GAGCCTCCCC CTGTGTCTCA     120

TGTGAAGCTG CTGCTGCAGA AGGTGGAGTC GTTGCATGAG GGTGGGGGGA GTCGCTGCTG     180

TTTGATCTGC CTCTGCTCCC CATTCACACT CTCATTTCAT TCCCACGGAT CCACATTACA     240

ACTCGCCTTT AACCCTTTCC CTGGCGGAGC CCACGCGTCT TTCATCCCTC CTGCCGCGGC     300

CGCTGAGCGA CCAGAGCGCG ACATTGTTGC GGCGGGGGAT TGGGCGACAT TGTTGCGAAT     360

AATCGGAGCT GCTGGGGGGG AACTGATACA ACGTTGCGAC TGTAAAGGAA TTAACTCGGC     420

CGAATGGGAT TTTATCTGTG TCGGTGAGAG AAGCGGATCC CAGGAGC ATG GGG GCG       476
                                                    Met Gly Ala
                                                      1

TCT GTA GCG CTG ACT TTT CTA CTT CTT CTT GCA ACT TTC CGC GCA GGC       524
Ser Val Ala Leu Thr Phe Leu Leu Leu Leu Ala Thr Phe Arg Ala Gly
  5                  10                  15

TCA GGA CAC GAT GAA GTG GAG ACA AGA GAG TGC ATC TAT TAC AAT GCC       572
Ser Gly His Asp Glu Val Glu Thr Arg Glu Cys Ile Tyr Tyr Asn Ala
 20                  25                  30                  35

AAC TGG GAA CTG GAG AAG ACC AAC CAA AGT GGG GTG GAA AGC TGC GAA       620
Asn Trp Glu Leu Glu Lys Thr Asn Gln Ser Gly Val Glu Ser Cys Glu
                 40                  45                  50

GGG GAA AAG GAC AAG CGA CTC CAC TGT TAC GCG TCT TGG AGG AAC AAT       668
Gly Glu Lys Asp Lys Arg Leu His Cys Tyr Ala Ser Trp Arg Asn Asn
             55                  60                  65

TCG GGC TTC ATA GAG CTG GTG AAA AAA GGA TGC TGG CTG GAT GAC TTC       716
Ser Gly Phe Ile Glu Leu Val Lys Lys Gly Cys Trp Leu Asp Asp Phe
         70                  75                  80

AAC TGT TAT GAC AGA CAG GAA TGT ATT GCC AAG GAA GAA AAC CCC CAA       764
Asn Cys Tyr Asp Arg Gln Glu Cys Ile Ala Lys Glu Glu Asn Pro Gln
     85                  90                  95
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GTC TTT TTC TGC TGC TGC GAG GGA AAC TAC TGC AAC AAG AAA TTT ACT          812
Val Phe Phe Cys Cys Cys Glu Gly Asn Tyr Cys Asn Lys Lys Phe Thr
100                 105                 110                 115

CAT TTG CCT GAA GTC GAA ACA TTT GAT CCG AAG CCC CAG CCG TCA GCC          860
His Leu Pro Glu Val Glu Thr Phe Asp Pro Lys Pro Gln Pro Ser Ala
                120                 125                 130

TCC GTA CTG AAC ATT CTG ATC TAT TCC CTG CTT CCA ATT GTT GGT CTT          908
Ser Val Leu Asn Ile Leu Ile Tyr Ser Leu Leu Pro Ile Val Gly Leu
            135                 140                 145

TCC ATG GCA ATT CTC CTG GCG TTC TGG ATG TAC CGT CAT CGA AAG CCT          956
Ser Met Ala Ile Leu Leu Ala Phe Trp Met Tyr Arg His Arg Lys Pro
        150                 155                 160

CCC TAC GGG CAT GTA GAG ATC AAT GAG GAC CCC GGT CTG CCC CCT CCA         1004
Pro Tyr Gly His Val Glu Ile Asn Glu Asp Pro Gly Leu Pro Pro Pro
    165                 170                 175

TCT CCT CTG GTC GGG CTG AAG CCG CTG CAG TTG CTG GAG ATA AAG GCG         1052
Ser Pro Leu Val Gly Leu Lys Pro Leu Gln Leu Leu Glu Ile Lys Ala
180                 185                 190                 195

CGA GGC CGT TTC GGT TGC GTC TGG AAA GCT CGT CTG CTG AAT GAA TAT         1100
Arg Gly Arg Phe Gly Cys Val Trp Lys Ala Arg Leu Leu Asn Glu Tyr
                200                 205                 210

GTC GCA GTG AAA ATC TTC CCC GTG CAG GAT AAG CAG TCG TGG CAG TGT         1148
Val Ala Val Lys Ile Phe Pro Val Gln Asp Lys Gln Ser Trp Gln Cys
            215                 220                 225

GAG AAA GAG ATC TTC ACC ACG CCG GGC ATG AAA CAT GAA AAC CTA TTG         1196
Glu Lys Glu Ile Phe Thr Thr Pro Gly Met Lys His Glu Asn Leu Leu
        230                 235                 240

GAG TTC ATT GCC GCT GAG AAG AGG GGA AGC AAC CTG GAG ATG GAG CTG         1244
Glu Phe Ile Ala Ala Glu Lys Arg Gly Ser Asn Leu Glu Met Glu Leu
    245                 250                 255

TGG CTC ATC ACT GCA TTT CAT GAT AAG GGT TCT CTG ACG GAC TAC CTG         1292
Trp Leu Ile Thr Ala Phe His Asp Lys Gly Ser Leu Thr Asp Tyr Leu
260                 265                 270                 275

AAA GGG AAC TTG GTG AGC TGG AAT GAA CTG TGT CAC ATA ACA GAA ACA         1340
Lys Gly Asn Leu Val Ser Trp Asn Glu Leu Cys His Ile Thr Glu Thr
                280                 285                 290

ATG GCT CGT GGG CTG GCC TAC TTA CAT GAA GAT GTG CCC CGC TGT AAA         1388
Met Ala Arg Gly Leu Ala Tyr Leu His Glu Asp Val Pro Arg Cys Lys
            295                 300                 305

GGT GAA GGG CAC AAA CCT GCA ATC GCT CAC AGA GAT TTT AAA AGT AAG         1436
Gly Glu Gly His Lys Pro Ala Ile Ala His Arg Asp Phe Lys Ser Lys
        310                 315                 320

AAT GTA TTG CTA AGA AAC GAC CTG ACT GCG ATA TTA GCA GAC TTC GGG         1484
Asn Val Leu Leu Arg Asn Asp Leu Thr Ala Ile Leu Ala Asp Phe Gly
    325                 330                 335

CTG GCC GTA CGA TTT GAG CCT GGA AAA CCT CCG GGA GAT ACA CAC GGG         1532
Leu Ala Val Arg Phe Glu Pro Gly Lys Pro Pro Gly Asp Thr His Gly
340                 345                 350                 355

CAG GTT GGC ACC AGG AGG TAT ATG GCT CCT GAG GTT CTA GAG GGA GCA         1580
Gln Val Gly Thr Arg Arg Tyr Met Ala Pro Glu Val Leu Glu Gly Ala
                360                 365                 370
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ATT AAC TTT CAG CGA GAT TCC TTT CTC AGG ATA GAT ATG TAT GCC ATG      1628
Ile Asn Phe Gln Arg Asp Ser Phe Leu Arg Ile Asp Met Tyr Ala Met
            375                 380                 385

GGA CTG GTA CTC TGG GAA ATA GTA TCC CGA TGT ACA GCA GCA GAT GGG      1676
Gly Leu Val Leu Trp Glu Ile Val Ser Arg Cys Thr Ala Ala Asp Gly
        390                 395                 400

CCA GTA GAT GAG TAT CTG CTC CCA TTC GAA GAA GAG ATT GGG CAA CAT      1724
Pro Val Asp Glu Tyr Leu Leu Pro Phe Glu Glu Glu Ile Gly Gln His
    405                 410                 415

CCT TCC CTA GAG GAT CTG CAA GAA GTT GTC GTT CAC AAG AAG ATA CGC      1772
Pro Ser Leu Glu Asp Leu Gln Glu Val Val Val His Lys Lys Ile Arg
420                 425                 430                 435

CCT GTA TTC AAA GAC CAC TGG CTG AAA CAC CCT GGT CTG GCC CAA CTG      1820
Pro Val Phe Lys Asp His Trp Leu Lys His Pro Gly Leu Ala Gln Leu
                440                 445                 450

TGC GTC ACC ATT GAA GAA TGC TGG GAC CAT GAT GCG GAA GCA CGG CTT      1868
Cys Val Thr Ile Glu Glu Cys Trp Asp His Asp Ala Glu Ala Arg Leu
            455                 460                 465

TCG GCA GGC TGC GTA GAG GAG CGT ATT TCC CAA ATC CGT AAA TCA GTG      1916
Ser Ala Gly Cys Val Glu Glu Arg Ile Ser Gln Ile Arg Lys Ser Val
        470                 475                 480

AAC GGC ACT ACC TCG GAC TGC CTT GTA TCC ATT GTT ACA TCT GTC ACC      1964
Asn Gly Thr Thr Ser Asp Cys Leu Val Ser Ile Val Thr Ser Val Thr
    485                 490                 495

AAT GTG GAC TTG CCG CCC AAA GAG TCC AGT ATC TGAGGTTTCT TTGGTCTTTC    2017
Asn Val Asp Leu Pro Pro Lys Glu Ser Ser Ile ___ ___ - - -
500                 505                 510

CAGACTCAGT GACTTTTAAA AAAAAAACTC ACGAATGCAG CTGCTATTTT ATCTTGACTT    2077

TTTAATATTT TTTTTCTTGG ATTTTACTTG GATCGGATCA ATTTACCAGC ACGTCATTCG    2137

AAAGTATTAA AAAAAAAAAA CAAAACAAAA AAGCAAAAAC AGACATCTCA GCAAGCATTC    2197

AGGTGCCGAC TTATGAATGC CAATAGGTGC AGGAACTTCA GAACCTCAAC AAACTCATTT    2257

CTAGAGAATG TTCTCCTGGT TTCCTTTATC TCAGAAGAGG ACCCATAGGA AAACACCTAA    2317

GTCAAGCAAA TGCTGCAG                                                  2335
```

(2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 510 amino acids
(B) TYPE: amino acid
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

```
Met Gly Ala Ser Val Ala Leu Thr Phe Leu Leu Leu Leu Ala Thr Phe
  1               5                  10                  15

Arg Ala Gly Ser Gly His Asp Glu Val Glu Thr Arg Glu Cys Ile Tyr
            20                  25                  30
```

Tyr Asn Ala Asn Trp Glu Leu Glu Lys Thr Asn Gln Ser Gly Val Glu
35 40 45

Ser Cys Glu Gly Glu Lys Asp Lys Arg Leu His Cys Tyr Ala Ser Trp
50 55 60

Arg Asn Asn Ser Gly Phe Ile Glu Leu Val Lys Lys Gly Cys Trp Leu
65 70 75 80

Asp Asp Phe Asn Cys Tyr Asp Arg Gln Glu Cys Ile Ala Lys Glu Glu
85 90 95

Asn Pro Gln Val Phe Phe Cys Cys Cys Glu Gly Asn Tyr Cys Asn Lys
100 105 110

Lys Phe Thr His Leu Pro Glu Val Glu Thr Phe Asp Pro Lys Pro Gln
115 120 125

Pro Ser Ala Ser Val Leu Asn Ile Leu Ile Tyr Ser Leu Leu Pro Ile
130 135 140

Val Gly Leu Ser Met Ala Ile Leu Leu Ala Phe Trp Met Tyr Arg His
145 150 155 160

Arg Lys Pro Pro Tyr Gly His Val Glu Ile Asn Glu Asp Pro Gly Leu
165 170 175

Pro Pro Pro Ser Pro Leu Val Gly Leu Lys Pro Leu Gln Leu Leu Glu
180 185 190

Ile Lys Ala Arg Gly Arg Phe Gly Cys Val Trp Lys Ala Arg Leu Leu
195 200 205

Asn Glu Tyr Val Ala Val Lys Ile Phe Pro Val Gln Asp Lys Gln Ser
210 215 220

Trp Gln Cys Glu Lys Glu Ile Phe Thr Thr Pro Gly Met Lys His Glu
225 230 235 240

Asn Leu Leu Glu Phe Ile Ala Ala Glu Lys Arg Gly Ser Asn Leu Glu
245 250 255

Met Glu Leu Trp Leu Ile Thr Ala Phe His Asp Lys Gly Ser Leu Thr
260 265 270

Asp Tyr Leu Lys Gly Asn Leu Val Ser Trp Asn Glu Leu Cys His Ile
275 280 285

Thr Glu Thr Met Ala Arg Gly Leu Ala Tyr Leu His Glu Asp Val Pro
290 295 300

Arg Cys Lys Gly Glu Gly His Lys Pro Ala Ile Ala His Arg Asp Phe
305 310 315 320

Lys Ser Lys Asn Val Leu Leu Arg Asn Asp Leu Thr Ala Ile Leu Ala
325 330 335

Asp Phe Gly Leu Ala Val Arg Phe Glu Pro Gly Lys Pro Pro Gly Asp
340 345 350

Thr His Gly Gln Val Gly Thr Arg Arg Tyr Met Ala Pro Glu Val Leu
355 360 365

Glu Gly Ala Ile Asn Phe Gln Arg Asp Ser Phe Leu Arg Ile Asp Met
370 375 380

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Tyr Ala Met Gly Leu Val Leu Trp Glu Ile Val Ser Arg Cys Thr Ala
385                 390                 395                 400

Ala Asp Gly Pro Val Asp Glu Tyr Leu Leu Pro Phe Glu Glu Glu Ile
                405                 410                 415

Gly Gln His Pro Ser Leu Glu Asp Leu Gln Glu Val Val Val His Lys
            420                 425                 430

Lys Ile Arg Pro Val Phe Lys Asp His Trp Leu Lys His Pro Gly Leu
        435                 440                 445

Ala Gln Leu Cys Val Thr Ile Glu Glu Cys Trp Asp His Asp Ala Glu
    450                 455                 460

Ala Arg Leu Ser Ala Gly Cys Val Glu Glu Arg Ile Ser Gln Ile Arg
465                 470                 475                 480

Lys Ser Val Asn Gly Thr Thr Ser Asp Cys Leu Val Ser Ile Val Thr
                485                 490                 495

Ser Val Thr Asn Val Asp Leu Pro Pro Lys Glu Ser Ser Ile
            500                 505                 510
```

SEQ ID NO.: 5

DLKPEN

SEQ ID NO.: 6

G(T/S)XX(Y/F)X

SEQ ID NO.: 7

DIKSKN

SEQ ID NO.: 8

GTRRYM

SEQ ID NO.: 9

DLAARN

SEQ ID NO.: 10

XP(I/V)(K/R)W(T/M)

That which is claimed is:

1. A novel receptor protein characterized by having the following domains, reading from the N-terminal end of said protein:

an extracellular, ligand-binding domain,

a hydrophobic, trans-membrane domain, and

an intracellular, receptor domain having serine kinase-like activity.

2. A protein according to Claim 1, further comprising a second hydrophobic domain at the amino terminus thereof.

3. A protein according to Claim 1, wherein said protein is further characterized by having sufficient binding affinity for at least one member of the activin/TGF-ß superfamily of polypeptide growth factors such that concentrations of ≤ 10 nM of said polypeptide growth factor occupy ≥ 50% of the binding sites of said receptor protein.

4. A protein according to Claim 3, wherein said protein is further characterized by:

having a greater binding affinity for activins than for inhibins,

having substantially no binding affinity for transforming growth factors-ß, and

having substantially no binding affinity for non-activin-like proteins.

5. A protein according to Claim 1 having an amino acid sequence substantially the same as set forth in Sequence ID No. 2, Sequence ID No. 2', or Sequence ID No. 4.

6. A soluble, extracellular, ligand-binding protein, further characterized by:

having a sufficient binding affinity for at least one member of the activin/TGF-ß superfamily of polypeptide growth factors such that concentrations of ≤ 10 nM of said polypeptide growth factor occupy ≥ 50% of the binding sites on said receptor protein, and

having at least about 30% sequence identity with respect to:

the sequence of amino acids 20-134 set forth in Sequence ID No. 2;

the sequence of amino acids 20-134 set forth in Sequence ID No. 2, wherein the arginine residue at position number 39 is replaced by a lysine, and the isoleucine at residue number 92 is replaced by a valine; or

the sequence of amino acids 21-132 set forth in Sequence ID No. 4.

7. A protein according to Claim 6, further characterized by:

having a greater binding affinity for activins than for inhibins,

having substantially no binding affinity for transforming growth factors-ß, and

having substantially no binding affinity for non-activin-like proteins.

8. A protein according to Claim 6 wherein said protein comprises in the range of about 114-118 amino acids.

9. A DNA encoding a mature protein according to Claim 1.

10. A DNA encoding a mature protein according to Claim 3.

11. A DNA encoding a precursor-form of the protein of Claim 1.

12. A DNA encoding a protein according to Claim 2.

13. A DNA encoding a soluble protein according to Claim 6.

14. A DNA encoding a soluble protein according to Claim 8.

15. A DNA encoding a precursor-form of the protein of Claim 6.

16. A DNA according to Claim 9 having a contiguous nucleotide sequence substantially the same as:

nucleotides 128 - 1609 of Sequence ID No. 1;

variations of nucleotides 128 - 1609 of Sequence ID No. 1, wherein the codon for residue number 39 of the encoded amino acid codes for lysine, the codon for residue number 92 of the encoded amino acid codes for valine, and the codon for residue number 288 of the encoded amino acid encodes glutamine;

nucleotides 528 - 1997 of Sequence ID No. 3; or

variations of any of the above sequences which encode the same amino acid sequences, but employ different codons for some of the amino acids.

17. A DNA according to Claim 9 having a contiguous nucleotide sequence substantially the same as:

nucleotides 71 - 1609 of Sequence ID No. 1;

variations of nucleotides 71 - 1609 of Sequence ID No. 1, wherein the codon for residue number 39 of the encoded amino acid codes for lysine, the codon for residue number 92 of the encoded amino acid codes for valine, and the codon for residue number 288 of the

encoded amino acid encodes glutamine;

nucleotides 468 - 1997 of Sequence ID No. 3; or

variations of any of the above sequences which encode the same amino acid sequences, but employ different codons for some of the amino acids.

18. A DNA according to Claim 9 having a contiguous nucleotide sequence substantially the same as set forth in Sequence ID No. 1, Sequence ID No. 1' or Sequence ID No. 3.

19. A DNA according to Claim 13 having a contiguous nucleotide sequence substantially the same as nucleotides 71 - 127 of Sequence ID No. 1, or nucleotides 468-527 of Sequence ID No. 3.

20. A method for the recombinant production of activin receptor(s), said method comprising

expressing the DNA of Claim 9 in a suitable host cell.

21. A method for the recombinant production of soluble activin receptor(s), said method comprising

expressing the DNA of Claim 13 in a suitable host cell.

22. A DNA fragment useful as a hybridization probe, wherein said DNA fragment comprises at least a portion of the DNA according to Claim 9, and wherein said DNA fragment is labeled with a readily detectable substituent.

23. A DNA fragment according to Claim 22 wherein said readily detectable substituent is selected from a radiolabeled molecule, a fluorescent molecule, an enzyme, or a ligand.

24. A method to identify clones encoding receptors of the activin/TGF-β superfamily, said method comprising:

screening a genomic or cDNA library with a DNA fragment according to Claim 22 under low stringency hybridization conditions, and

identifying those clones which display a substantial degree of hybridization to said DNA fragment.

25. A method for screening a collection of compounds to determine those compounds which bind to receptors of the activin/TGF-ß superfamily, said method comprising employing the receptor of claim 1 in a competitive binding assay.

26. A bioassay for evaluating whether compounds are agonists for receptor protein(s) according to Claim 1, or functional modified forms of said receptor protein(s), said bioassay comprising:

(a) culturing cells containing:

DNA which expresses said receptor protein(s) or functional modified forms of said receptor protein(s), and

DNA encoding a hormone response element operatively linked to a reporter gene,

wherein said culturing is carried out in the presence of at least one compound whose ability to induce transcription activation activity of said receptor protein is sought to be determined; and thereafter

(b) monitoring said cells for expression of said reporter gene.

27. A bioassay for evaluating whether compounds are antagonists for receptor protein(s) according to Claim 1, or functional modified forms of said receptor protein(s), said bioassay comprising:

(a) culturing cells containing:

DNA which expresses said receptor protein(s), or functional modified forms of said receptor protein(s), and

DNA encoding a hormone response element operatively linked to a reporter gene;

wherein said culturing is carried out in the presence of:

increasing concentrations of at least one compound whose ability to inhibit transcription activation of said receptor protein(s) is sought to be determined, and

a fixed concentration of at least one agonist for said receptor protein(s), or functional modified forms of said receptor protein(s); and thereafter

(b) monitoring in said cells the level of expression of the product of said reporter gene as a function of the concentration of said compound, thereby indicating the ability of said compound to inhibit activation of transcription.

28. A method for modulating the transcription trans-activation of activin receptor(s), said method comprising:

contacting said receptor with an effective, modulating amount of the protein of Claim 6.

29. An antibody generated against the protein of Claim 6.

30. An antibody according to Claim 29, wherein said antibody is a monoclonal antibody.

31. A method for modulating the transcription trans-activation of activin receptor(s), said method comprising:

contacting said receptor with a modulating, effective amount of the antibody of Claim 29.

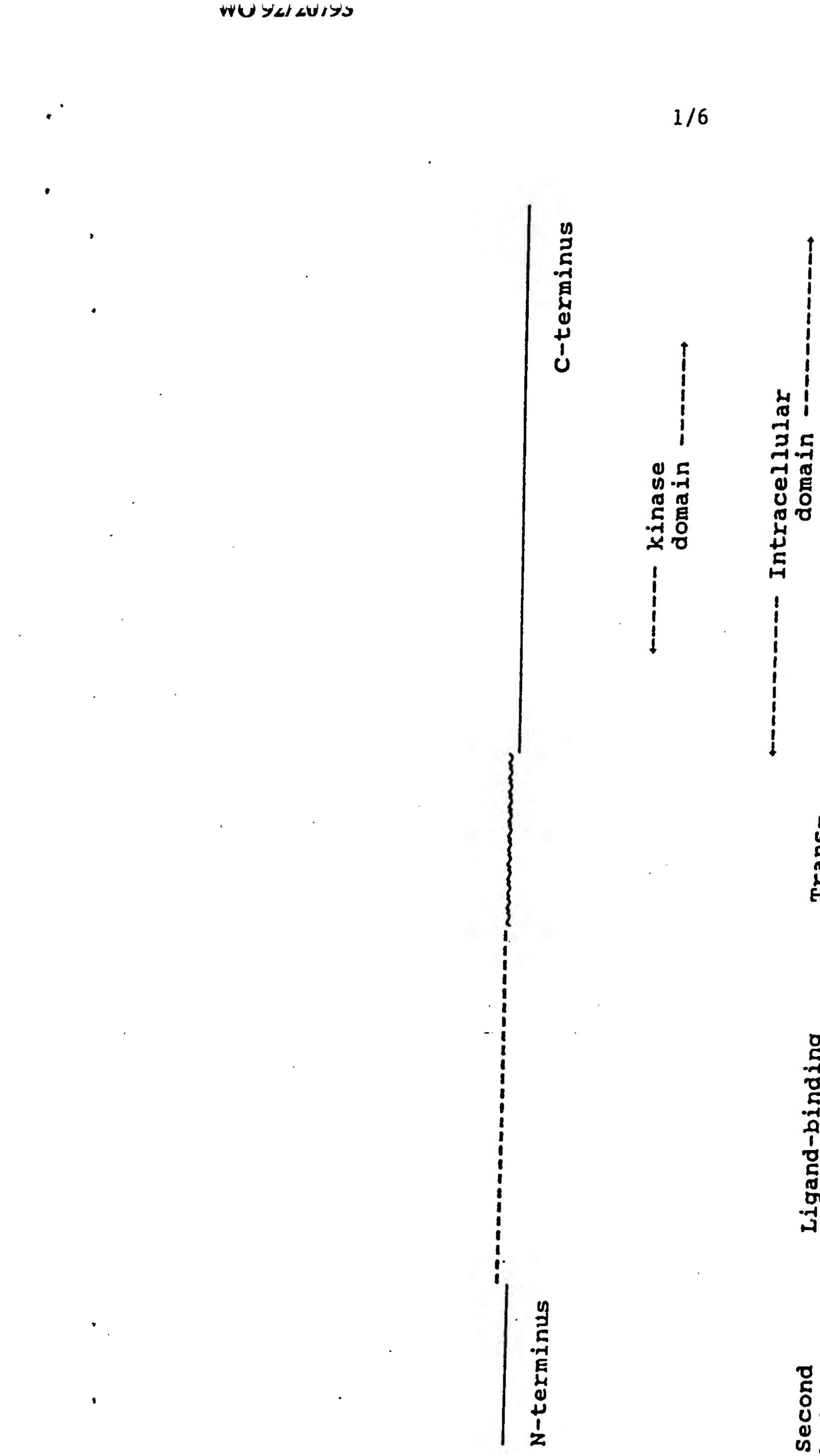
C-terminus
Kinase domain
Intracellular domain
Trans-membrane domain
Ligand-binding domain
Second hydrophobic domain
N-terminus

Figure 1

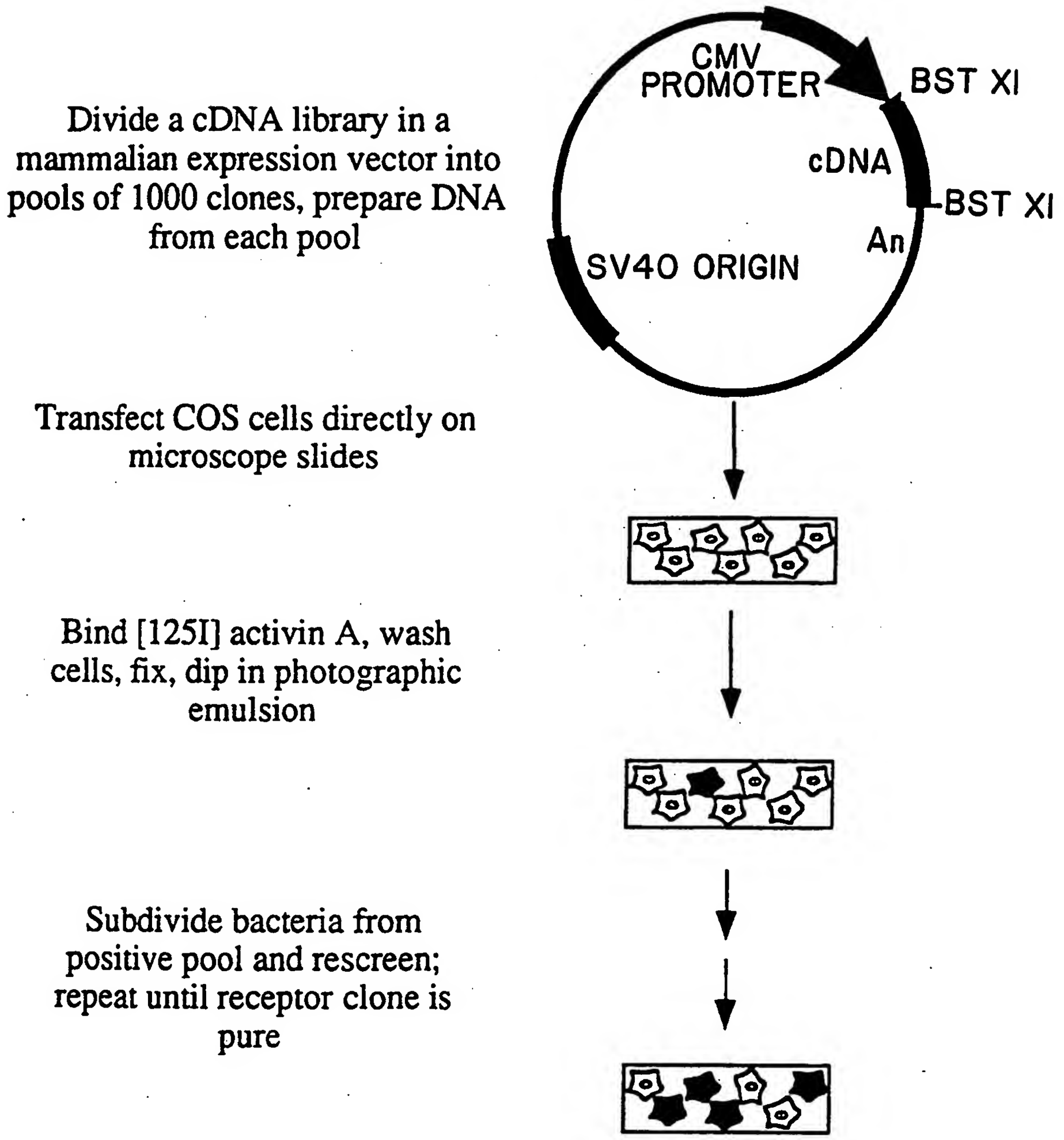
Divide a cDNA library in a mammalian expression vector into pools of 1000 clones, prepare DNA from each pool
CMV PROMOTER
BST XI
cDNA
BST XI
An
SV40 ORIGIN
Transfect COS cells directly on microscope slides
Bind [125I] activin A, wash cells, fix, dip in photographic emulsion
Subdivide bacteria from positive pool and rescreen; repeat until receptor clone is pure

FIG. 2

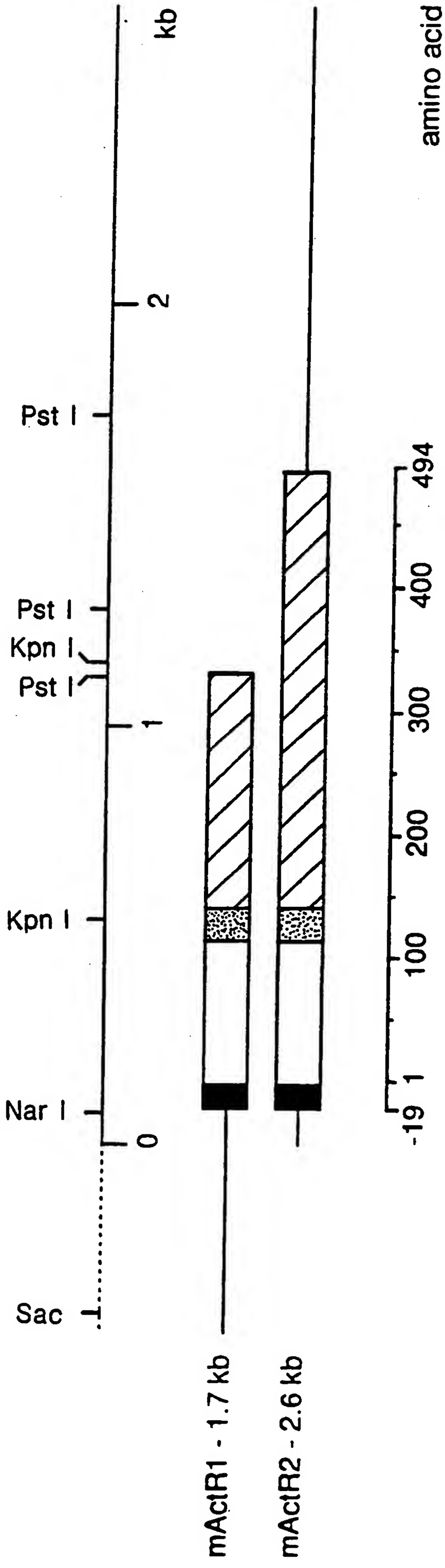
kb
2
Pst I
Pst I
Kpn I
Pst I
1
Kpn I
Nar I
0
Sac I
amino acid
494
400
300
200
100
-19 1
mActR1 - 1.7 kb
mActR2 - 2.6 kb

FIG. 3

4 / 6

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                       *  *  *  *          *  *                   *                   *
Act R      (174) L LLEVKGRFGFVCVWKAQLLENVAVKIFFPIDDKQSWQEEEEVYSLPGMHHNNLLQFIGAEKRGTSVDVDLWLITA
Daf        (295  L LTGRVGRFGFVNVSRGDYIEGVAVKIFFNADDEPAFHEEEEIFETRMLHHNNLLRYIGSDRVITGFVTELWLVTE
Subdomain            I                  II           III                IV

                                  *  **                   *  *      **         *  ***
Act R      HFHGSLSDFLFLNAVVVSWNELCHIAETAAGLAALHHEIIGGKKDGKPAAIHRDIKSKNVLLKNNLTTAC[illegible]GL
Daf        HYHGSLSDFLFLNEVTVNIETYYNLMRSAAGLAALHHNIIGGKKESKPAAMHRDIKSKNIIMKNNLTTCA[illegible]IGL
Subdomain   V                    VIA                           VIB                    VII

                           *   *  ***                       *    *
Act R      LALKF..AEAGKSAGDTHGGGTTRYMAPEVLLEGAIFFQR.DAFLRDDIYAMGLVLWELASRCTAADGPVDEYMLP
Daf        LSLSKPEAAASDIIANENYKGTTRYMAPEVLLNSTMFFTVFESYQCDDVYSFGLVLWEITLRC..EDGIVLPREAA
Subdomain                   VIII                               IX

                                                           *          *
Act R      FE..E.EEIGPHPSLEDMQVVVVHKKKRPVLRDWWQKHAMMAMLEETIIECWDHDAEARLSAGCVGERITQMQRL (28)
Daf        TVIPEIEWTDPDPQDMMMEVVCTRRRPPTENPWWKHHPMMKHIEEEIIKCWNGNPSARFTSYICRKRMDERQQL (78)
Subdomain   X                                                    XI
```

FIG. 4

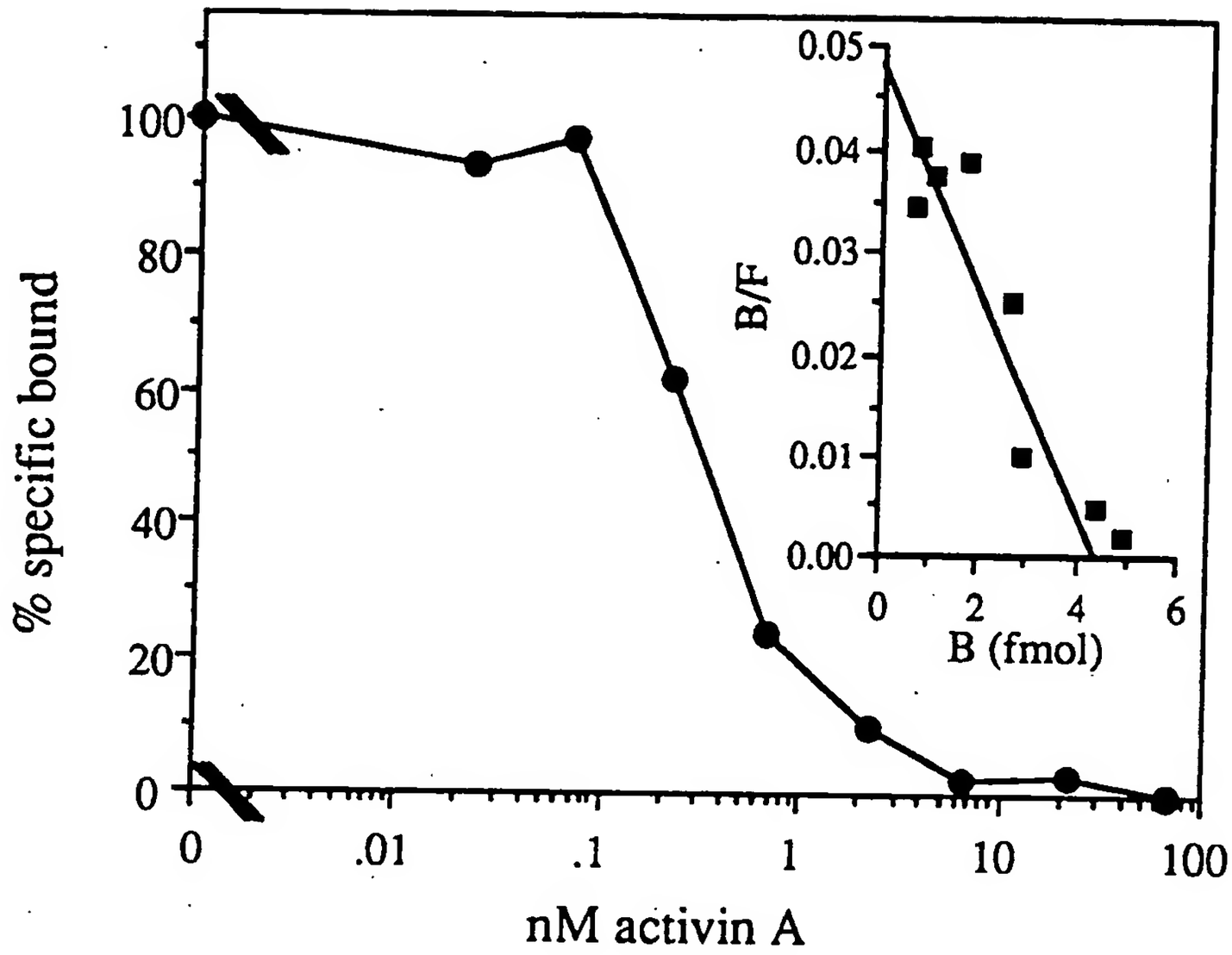
% specific bound
100
80
60
40
20
0
0
.01
.1
1
10
100
nM activin A
B/F
0.05
0.04
0.03
0.02
0.01
0.00
0
2
4
6
B (fmol)

FIG. 5A

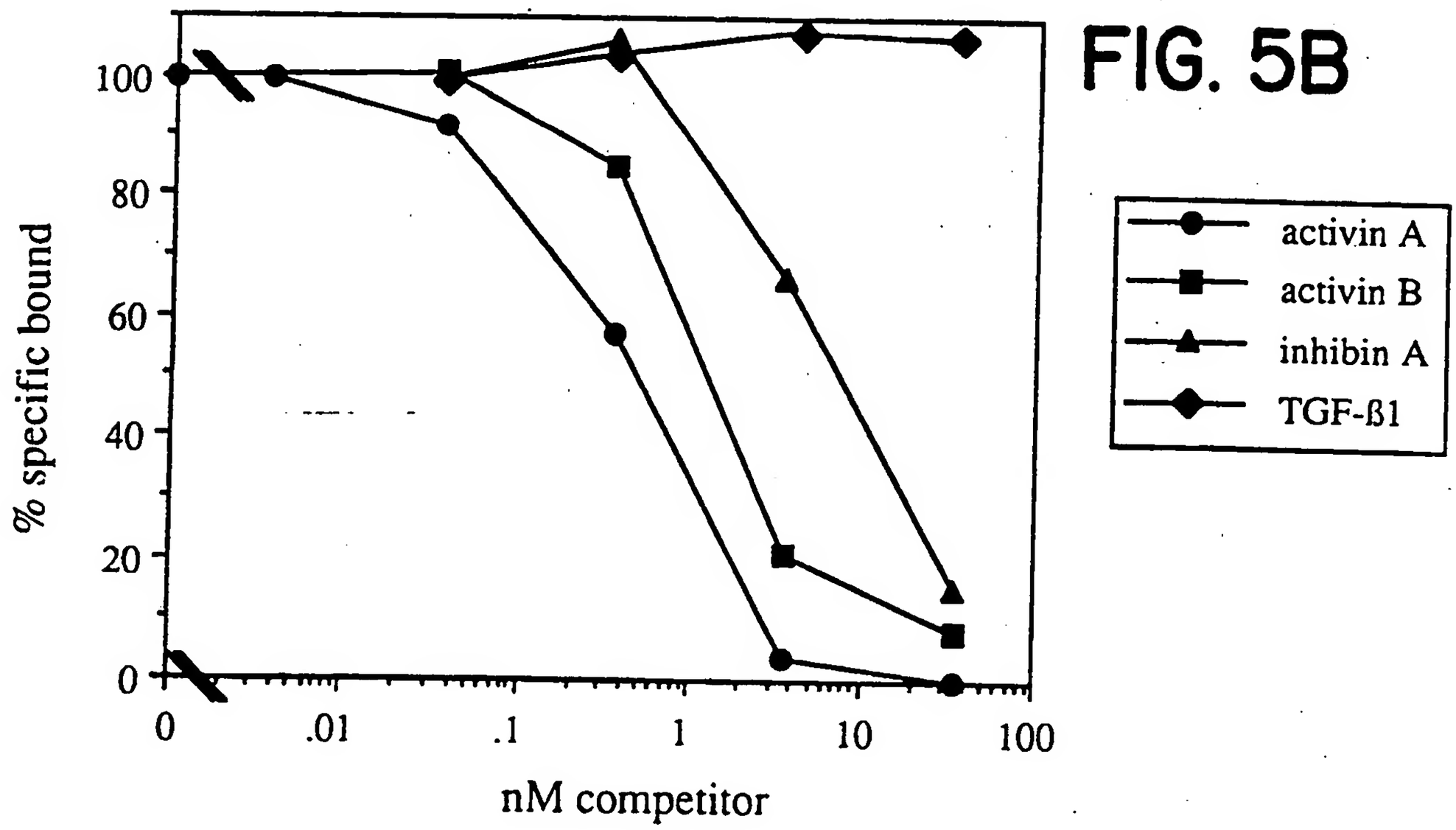
% specific bound
100
80
60
40
20
0
0
.01
.1
1
10
100
nM competitor
activin A
activin B
inhibin A
TGF-ß1

FIG. 5B

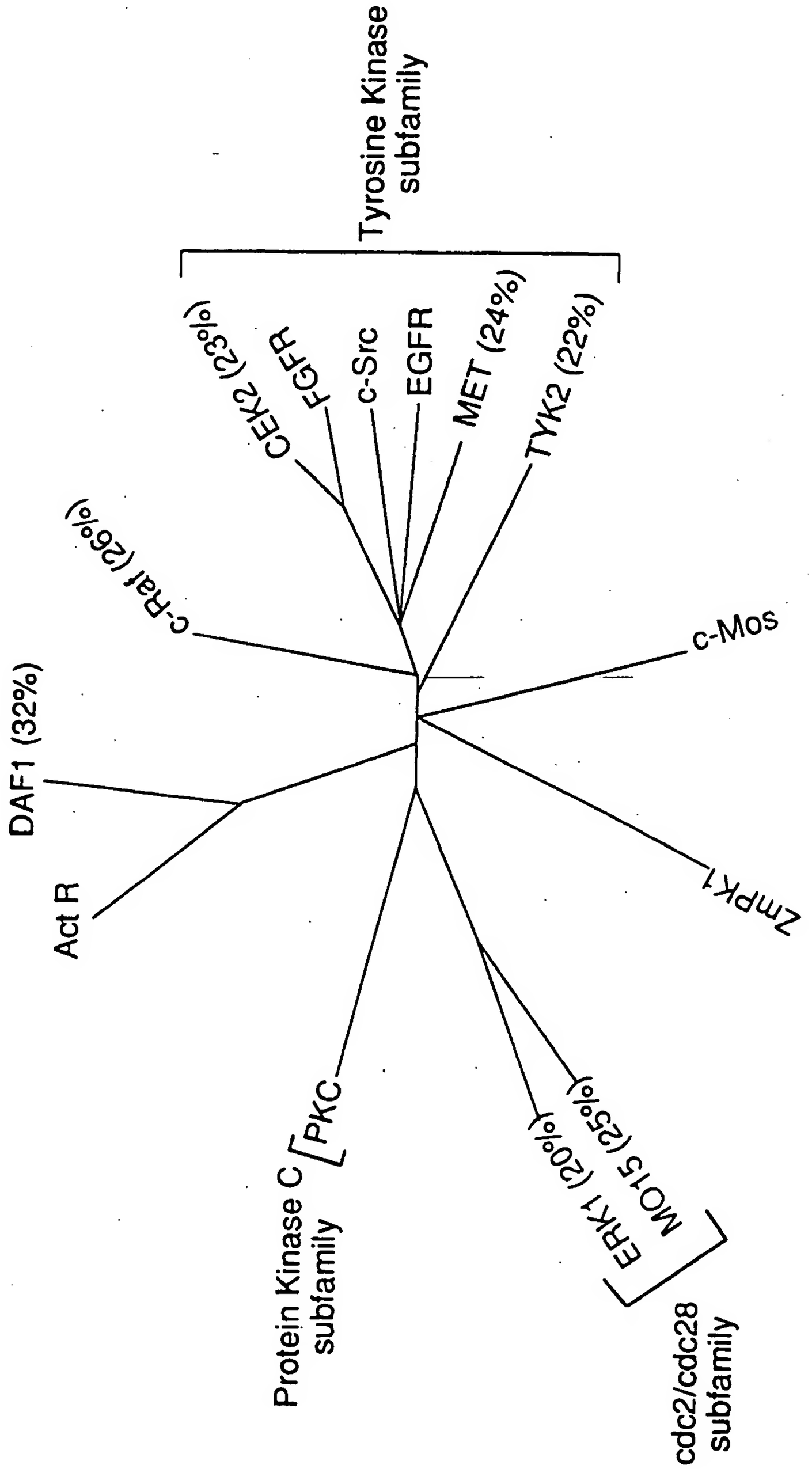
Tyrosine Kinase subfamily
CEK2 (23%)
FGFR
c-Src
EGFR
MET (24%)
TYK2 (22%)
c-Raf (26%)
c-Mos
ZMPK1
DAF1 (32%)
Act R
Protein Kinase C subfamily
PKC
ERK1 (20%)
MO15 (25%)
cdc2/cdc28 subfamily

FIG. 6

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 C12N15/12; C07K15/00; C12Q1/68; G01N33/53
C12N15/62; A61K37/02; C12P21/08; A61K39/395

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	C12N ; C07K ; C12P ; C12Q G01N ; A61K

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
X	CELL vol. 61, no. 3, 18 May 1990, CAMBRIDGE, MA, US pages 635 - 645; L. GEORGI ET AL.: 'daf-1, a C. elegans gene controlling Dauer larva development, encodes a novel receptor protein kinase.' cited in the application see abstract; figures 4,6	1,2,9, 11,12
X	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS. vol. 157, no. 2, 15 December 1988, DULUTH, MN, US pages 844 - 849; C. CAMPEN ET AL.: 'Characterization of activin A binding sites on the human leukemia cell line K562.' see the whole document	1-4,25

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° Special categories of cited documents :[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
16 SEPTEMBER 1992	29. 09. 92
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	NOOIJ F.J.M.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
P,X	SCIENCE. vol. 255, no. 5052, 27 March 1992, WASHINGTON DC, US pages 1702 - 1705; L. MATHEWS ET AL.: 'Cloning of a second type of activin receptor and functional characterization in Xenopus embryos.' see abstract; figure 1	1-5, 9-12,20, 25
P,X	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS. vol. 184, no. 1, 15 April 1992, DULUTH, MN, US pages 310 - 316; C. DONALDSON ET AL.: 'Molecular cloning and binding properties of the human type II activin receptor.' see abstract; figure 2	1-5, 9-12, 16-20, 22-24
P,X	CELL vol. 68, no. 4, 21 February 1992, CAMBRIDGE, MA, US pages 775 - 785; H. LIN ET AL.: 'Expression cloning of the TGF-beta type II receptor, a functional transmembrane serine/threonine kinase.' see abstract; figures 2,5,6	1-3, 9-12, 22-24
P,X	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS. vol. 181, no. 2, 16 December 1991, DULUTH, MN, US pages 684 - 690; M. KONDO ET AL.: 'Activin receptor mRNA is expressed early in Xenopus embryogenesis and the level of the expression affects the body axis formation.' see abstract; figure 1	1-5, 9-12, 16-18, 20,22-24

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

Although claims 28 and 31 (both practically, as far as an in vivo method is concerned) are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searches without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.